



Qualification of innovative floating substructures for 10MW wind turbines and water depths greater than 50m

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Definitions & Abbreviations

ABS	American Bureau of Shipping
ANEMOC	Atlas Numérique d'États de mer Océaniques et Côtiers
ASL	Above Sea Level
AST	Administrative Support Team
CENER	Centro Nacional de Energías Renovables
CETMEF	Centre d'études techniques maritimes et fluviales
COADS	The Comprehensive Ocean Atmosphere Dataset
DLC	Design Load Cases
DNV	Det Norske Veritas
DTU	Technical university of Denmark
ECMWF	European Centre for Medium-Range Weather Forecasts
EHWL	Extreme High Water Level
ELW L	Extreme Low Water Level
EUNIS	European Nature Information System
EWTSII	European Wind Turbine Standard II
GdF	Golfe de Fos
GoM	Gulf of Maine
HAT	Highest Astronomical Tide
HSE	Health and Safety Executive
IEC:	International Electrotechnical Commission
IFREMER:	French Research Institute for Exploration of the Sea
LAT	Lowest Astronomical Tide
LSM	Least Square Method
MSL	Mean Sea Level
MW	Mega Watt
NERACOOS	Northeast Regional Association of Coastal and Ocean Observing Systems
NCE	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NORSOK	Norwegian petroleum industry Standards
NREL	National Renewable Energy Laboratory
NTM	Normal Turbulence Model
OPPE	Organismo Público de Puertos del Estado
SST	Sea Surface Temperature
PC	Project Coordinator
PM	Project Manager
SISMERS	Système d'information scientifique pour la mer
UMOOS	University of Maine Ocean Observing System
USGS	United States Geological Survey
VOF	Voluntary Observatory Fleet
WAUDIT	Wind resource assessment audit and standardization
WoB	West of Barra
WPL	Work Package Leader

Symbols

u	Wind Speed
u_{10}	Mean wind speed with averaging period of 10 minutes
u_{1-hour}	Mean wind speed with averaging period of 1 hour
v_{ref}	50-years return period 10-minutes wind speed
I_{ref}	reference turbulence intensity
z	Height
z_{hub}	Hub Height
H	Height
δ	Weibull location parameter
A	Weibull shape parameter
k	Weibull scale parameter
H_s	Significant wave height
$H_{s50years}$	50 year Return Period Significant Wave Height
T_p	Wave peak period
$T_{max,50year}$	Maximum 50 year peak period
$T_{min,50year}$	Minimum 50 year peak period
T_a	Air temperature
T_s	Sea surface temperature
T_f	Sea water freezing point
v_c	Mean surface current speed
$v_{c,wind}$	Current speed induced by wind
$v_{c,tide}$	Current speed induced by tides

Executive Summary

Met-ocean conditions and seabed characteristics greatly influence design of marine structures. Their adequate definition is thus crucial for the upscaling of the innovative floating substructure concepts of LIFES50+ to support a 10 MW turbine, as well as for the evaluation of their performance in a realistic range of operating parameters.

This report provides three sets of environmental parameters for moderate, medium and severe met-ocean conditions. To ensure sufficient realism and coherence between the different parameters, site-specific data is taken from three areas. By consensus decision of consortium partners, the areas selected are as follows:

- Site A (moderate met-ocean conditions), offshore of Golfe de Fos, France
- Site B (medium met-ocean conditions), the Gulf of Maine, United States of America
- Site C (severe met-ocean conditions) West of the Isle of Barra, Scotland

In-situ data sources were sparse for Site A, relative to sites B and C. Hence the evaluation of environmental parameters there relies primarily on published results, while for sites B and C buoy data has been used more extensively. It should be clear that the objective is not a complete site assessment for a real wind-farm project but rather to provide adequately realistic and coherent environmental parameters for upscaling and evaluating the platform concepts in moderate, medium and severe met-ocean conditions.

The table below summarises the proposed met-ocean conditions for the three sites.

	50-year wind hub height	at 50-year significant wave height	50-year sea-state peak period	50-year current	Extreme water level range	Soil
Site A	37	7.5	8-11	0.9	1.13	Sand/Clay
Site B	44	10.9	9-16	1.13	4.3	Sand/Clay
Site C	50	15.6	12-18	1.82	4.2	Basalt

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1 Objective

LIFES50+ project aims to optimize, qualify and evaluate four innovative substructure designs for 10MW turbines. Four concept designers already qualified to TRL>4 for a 5MW Wind Turbine will develop their designs to accommodate a 10MW wind turbine.

Task 1.1, “*Definition of the target locations: business cases*” of Work Package 1 “*Concept Development and optimization*”, aims to select three reference locations that can be used by the concept developers to conduct their designs and, simultaneously, to establish a common frame of comparison for their evaluation.

All four concepts have different target deployment areas. For instance, most suitable water depths are different for TLP and semisubmersible structures. On the other hand, there are different areas with the potential to become a commercial deployment area for floating offshore wind. Considering these facts, three different areas have been selected and analyzed.

In this deliverable, met-ocean information for these selected sites is gathered. This data will serve as a reference during the rest of the LIFES50+ project and in particular for the Load Cases definition.

Deliverable 1.1 reports the site selection process and summarizes the met-ocean characterization conducted for the target locations.

2 Site Selection Procedure

This section summarizes the site selection process that have been followed during the development of Task 1.1 “*Definition of the target locations: business cases*” in order to choose three sites for which the concept designers will further develop their concepts.

In general terms, the selection process can be summarized as follows:

- Each concept developer proposing several preferred sites. The only condition imposed to the designers was to propose sites for which a relevant source of met-ocean information was available, since a detailed oceanographic and meteorological characterization for the load cases definition is necessary.
- Definition of the general criteria that will drive the sites selection: Main criteria was having a wide range of environmental conditions (from severe to mild), site depths and soil conditions. It was also considered important that countries where the sites are intended to be located have shown support to the offshore wind or that, aprioristically, are well positioned to become a major market for floating offshore wind in the near future.
- Final decision: Taking into account the preference of each partner and the general criteria defined, three sites were finally selected. The next sections will further detail the aforementioned methodology:

2.1 General Description of the proposed sites

As a first step in the site selection process, each concept developer proposed different sites of their interest from which the final selected ones will be chosen. This first proposal is summarized in the following table:

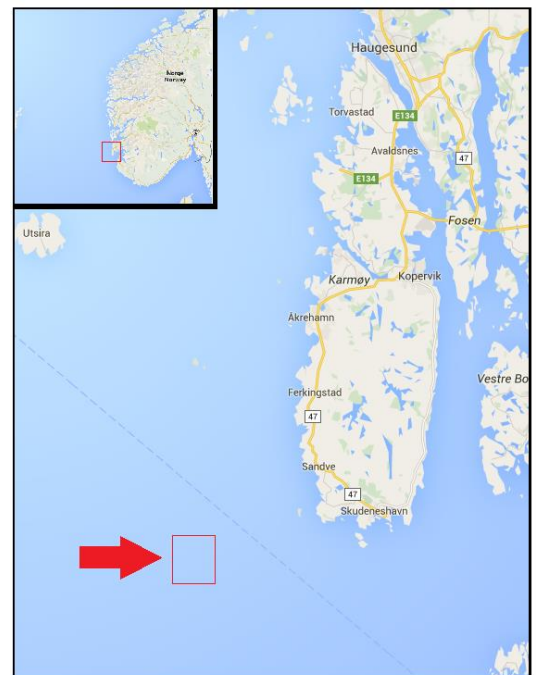
Concept developer	Proposed sites			
	Olav Olsen	Iberdrola	Tecnalia	Ideol
Sites proposed	<ul style="list-style-type: none"> • Karmøy (Norway) • Buchan Deep (Scotland) • BIMEP, Biscaya (Spain) • Plocan, Canary Island (Spain) • Gulf of Maine (USA) • Japan 	<ul style="list-style-type: none"> • Aberdeen (Scotland) • West of Barra (Scotland) • Golfe de Fos (France) • Massachusetts (USA) • Gulf of Maine (USA) 	<ul style="list-style-type: none"> • Plocan, Canary Island (Spain) • Buchan Deep (Scotland) • Gulf of Maine (USA) 	<ul style="list-style-type: none"> • East of Scotland • Golfe de Fos (France) • Plocan, Canary Island (Spain)

Table 1: Summary of the sites proposed by each concept developer

A preliminar assessment of the proposed sites was conducted in order to determine the main characteristics that define each site, such as data availability, general environmental conditions, depth range, government support to offshore wind, etc. in order to have enough information of each site to perform an appropriate selection. The main information gathered in this first study is summarized in the following paragraphs:

KARMØY (Norway):

- The Research Council of Norway is proposing an increase of NOK 1.1 billion for research in its input to the national budget for 2016, including research-based technology development for offshore wind
- *Hywind*¹ 2.3 Megawatt (MW) floating wind turbine was installed at this location in 2009 (The first full scale prototype) & *SWAY*² Prototype (0.15MW)
- Essential Met-ocean data:
 - Reference site depth: 200 m
 - 50 year reference significant wave height: High
 - 100 m height average wind speed: High
 - Seabed: no data



¹ <http://www.statoil.com/en/TechnologyInnovation>

² <http://www.sway.no/?page=165>

Aberdeen (Scotland)

- The Scottish Government has demonstrated high support to the Offshore Wind Market.
- Some test and demonstration sites have been defined at Aberdeen bay, Hunterston and Methil.
- Marine Scotland selected different sites with potential for the development of Floating Offshore Wind and Aberdeen was considered among them.
- Essential Met-ocean data:
 - Reference site depth: 70-120 m
 - 50 year reference significant wave height: 10,13 m
 - 100 m height average wind speed: higher than 9,3 m/s
 - Seabed: Sand

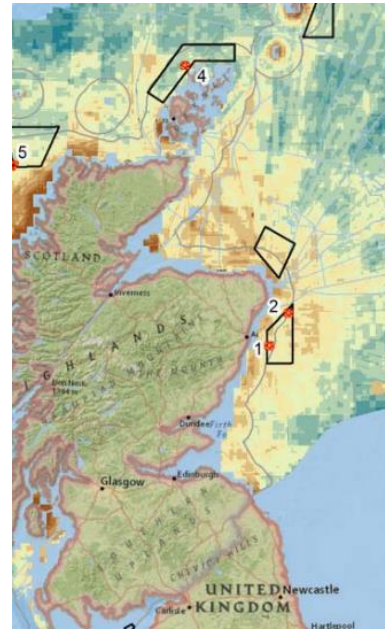


Figure 2: Aberdeen proposed site location

West of Barra (Scotland)

- The Scottish Government has demonstrated high supports to the Offshore Wind.
- Marine Scotland selected different sites with potential for the development of Floating Offshore Wind and West of Barra was considered among them.
- Essential Met-ocean data:
 - Reference site depth: 56-118 m
 - 50 year reference significant wave height: 13,59 m
 - 100 m height average wind speed: 11,26 m/s
 - Seabed: Rock

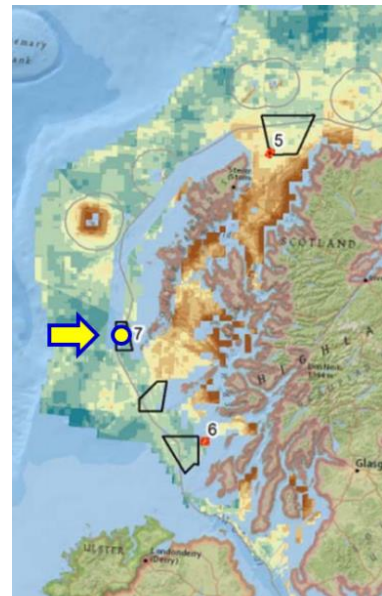


Figure 3: West of Barra proposed site location

Golfe de Fos (France)

- France's government stages a third Offshore Wind tender in 2015.
- France Energies Marines has implemented and coordinated two specific tests sites for FOWTs.
- Essential Met-ocean data:
 - Reference site depth: 60-70 m
 - 50 year reference significant wave height: 7,0
 - 100 m height average wind speed: higher than
 - Seabed: Sand/Mud

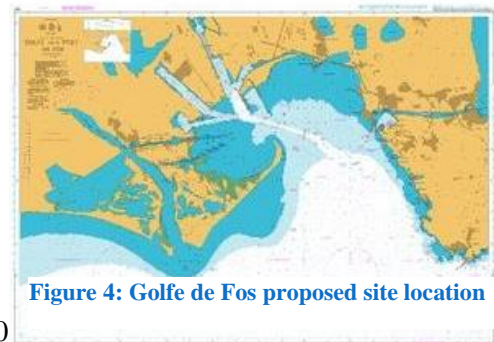


Figure 4: Golfe de Fos proposed site location

Plocan, Canary Island (Spain)

- BCE's NER300 program has awarded 2x30MM€ projects for developing Floating Offshore Wind into the Canary Island.
- Spain support to Renewable Energy stopped in 2013.
- Essential Met-ocean data:
 - Reference site depth: 50-100 m
 - 50 year reference significant wave height: 5,0 m
 - 100 m height average wind speed: 9,8 m/s
 - Seabed: Sand/Rock



Figure 5: Canary Island proposed site location

Gulf of Maine (USA)

- US is expected to become a major market for floating Offshore Wind.
- Gulf of Maine launched a few years ago one of the first Calls for Floating Wind projects.
- Essential Met-ocean data:
 - Reference site depth: 50-130 m
 - 50 year reference significant wave height: 10,0 m
 - 100 m height average wind speed: 9,8 m/s
 - Seabed: Sand/Mud/Rock

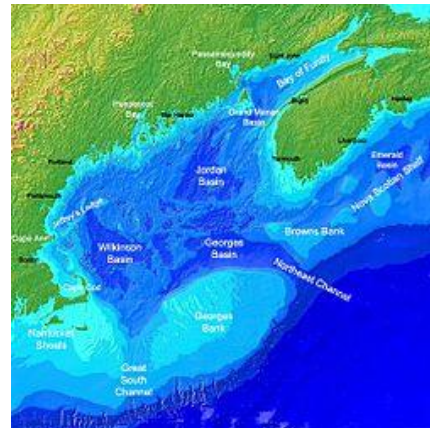


Figure 6: Gulf of Maine proposed site location

Massachusetts (USA)

- US will be a major market for floating Offshore Wind.
- Electrical network used for other offshore project in the area.
- A lease process has been launched last year for the Massachusetts WEA area (3.000 MW)
- Essential Met-ocean data:
 - Reference site depth: 60-200 m
 - 50 year reference significant wave height: 10,2 m
 - 100 m height average wind speed: 10 m/s
 - Seabed: Mud/Muddy/Sand



Figure 7: Massachusetts proposed site location

North of Honshu (Japan)

- Japan is a world leader in the sector.
- Fukushima FORWARD Wind Project³
- A 7MW WT V-Shaped (inside the Fukushima Forward Project) have be installed in September 2015.
- Essential Met-ocean data:
 - Reference site depth: No data
 - 50 year reference significant wave height: 12,0 m
 - 100 m height average wind speed: Low
 - Seabed: No data



Figure 8: North of Honshu proposed site location

The following table summarizes this data achieved for the preliminary characterization for each one of the proposed sites.

COUNTRY	AREA	SUPPORT	DATA AVAILABILITY	METOCEAN	DEPTH	SEABED	Hs_50years	Average Wind 100 m	Seabed
NORWAY	Karmøy	✓	?	~	200		High	High	
SCOTLAND	Scotland, West of Barra	✓	✓	~	56-118	ROCK	13.59	11.26	Rock
	Scotland, Aberdeen	✓	✓	~	70-120	SAND	10.13	>9.3	Sand
FRANCE	Golfe de Fos	✓	?	~	60-75	SAND/MUD	7	>10	Sand/Mud
SPAIN	Spain, Flocan (Canarias)	⚠	✓	~	50-100	SAND/ROCK	5	9.8	sand/rock
US	US, Gulf of Maine	✓	✓	~	50-130	SAND/MUD/ROCK	10	9.8	sand/mud/rock
	Massachussets WEA	⚠	⚠	~	60-200	MUD/MUDDY SAND	10.2	10	Mud/Muddy sand
JAPAN	Japan	✓	?	~	120	SAND	12	low	

Table 2: Summary table of proposed sites' main information

³ <http://www.fukushima-forward.jp/english/>

2.2 Site Selection Criteria and Site selection

This section reviews all the decisions and assumptions agreed during the meetings of the WP1, in regard to the selection of the sites for the development of the concepts' design. During these meetings, the main requirements to be accomplished by the final sites were established:

- **The met-ocean severity of the three finally selected sites shall be sufficiently diverse.** The overall idea was to have one site with severe environmental conditions, other with a moderate climate and a third site with mild met-ocean conditions.
- **Offshore sites shall be representative of a big range of market conditions.** This will be important since it will influence the cost assessment that will be conducted in WP2.
- **Site depth should be representative for each site and it must be different for the others' sites.** Therefore, a wide range of water depths shall be obtained with the three sites selected.
- **Countries should have shown interest on the offshore wind business.** It was considered that to correctly evaluate the future of floating wind business, the selected locations should be on countries where the floating wind market is expected to be developed in the coming years.

Since each developer has its own preferences and three sites shall eventually be selected, it was decided that each concept developer should vote for their three preferred sites (given to each one of them 3, 2 or 1 points respectively). Taking into account the main criteria previously established and the preferences of each designer, the final decision was taken.

In the table below, it is summarized the voting of each one of the developers:

COUNTRY	AREA	Olav Olsen	Iberdrola	Nautilus	Ideal	Total	Depth	Hs_50 years	Average Wind 100 m	Seabed
NORWAY	Karmøy	1 st				3	200	high	high	-
SCOTLAND	West of Barra		1 st	3 rd		4	56-118	13,59	11,26	Rock
	Aberdeen	2 nd			1 st	5	70-120	10,13	>9,3	Sand
FRANCE	Golfe de Fos		3 rd	1 st	2 nd	6	60-70	7	>10	Sand/Mud
SPAIN	Flocan (Canarias)					0	50-100	5	9,8	Sand/Rock
US	Gulf of Maine		2 nd	2 nd		4	50-130	10	9,8	Sand/Mud/Rock
	Massachusetts WEA					0	60-200	10,2	10	Mud/Muddy Sand
JAPAN	North of Honshu				3 rd	1		12	low	-
(*) The 1 st in the concept developers' column mean this is the first option for this developer, and gives 3 points to this site.										
(**) The 2 nd in the concept developers' column mean this is the second option for this developer, and gives 2 points to this site.										
(***) The 3 rd in the concept developers' column mean this is the third option for this developer, and gives 1 point to this site.										
(****) Olav Olsen only presents two preferred sites.										

Table 3: Review of the voting of the concept developers

As it is shown in the table above, the two sites with highest scores were Golfe de Fos (France) and Aberdeen (Scotland) but there was a tie in the third place between West of Barra (Scotland) and Gulf of Maine (US). In order to select three from these four pre-selected sites it was considered that:

- If possible, two sites in the same country should not be selected → Two sites in Scotland shall be avoided.
- The most differentiation between the sites should be sought. → Since the environmental conditions in Gulf of Maine and Aberdeen are quite similar, one of them shall be avoided.

Finally, it was decided to choose the three following sites achieving the most differentiation possible: **West of Barra (Scotland), Golfe de Fos (France) and Gulf of Maine (US)** being excluded the Aberdeen (Scotland) site.

COUNTRY	AREA	Support	Data Availability	Meteorology	Depth	Seabed	Hs_50 years	Average Wind 100 m	Seabed
SCOTLAND	Scotland, West of Barra		✓	☞	56-118	ROCK	13.59	11.26	Rock
FRANCE	Golfe de Fos	✓	✓	☞	60-75	SAND/MUD	7	>10	Sand/Mud
US	US, Gulf of Maine		✓	☞	50-130	SAND/MUD/ROCK	10		sand/mud/rock

Table 4: Summary of selected sites preliminary characterization

2.3 Description of the selected sites

Following table summarizes the preliminary information gathered up to the selection procedure finalization from each of the selected finally sites and prior to the characterization described in section 3.

			Gulf of Maine	West of Barra	Golfe de Fos
SITE	Depth	[m]	100-140	56-118	50-100
	Lowest Astronomical Tide	[m]	-0,256	-1,48	-
	Mean Sea Level	[m]	1,567	-	-
	Highest Astronomical Tide	[m]	3,233	3,16	-
WIND	Mean Annual Wind Speed at 100m ASL	[m/s]	10,18	11,26	>10m/s
	Mean Peak Wind Gust	[m/s]	68,58	-	Gust factor 1,4
CURRENT	Mean Annual Current Speed	[m/s]	0,17	-	-
SOIL	Type of soil		Mud/Clay or Sand	Rock	Sand or Mud
WAVES	Mean Annual Significant Wave Height	[m]	1,6	2,76	0,8
	Peak Period	[s]	3,80	10,05	4,5
	1 year Significant Wave Height	[m]	7,55	TBE*	3,4
	1 year Peak Period	[s]	9,98	TBE*	8,5
	50 years Significant Wave Height	[m]	10,48	14,27	7
	50 years Peak Period	[s]	12,09	14,96	9,5

(*)TBE=To Be Extrapolated

Table 5: Preliminary data of the three selected sites

Once the three sites were selected, two additional considerations were done in order to completely define the met-ocean characterization:

- Design Depth: The sites shall be characterized for a certain depth that should be on the range of real depths of the site. This consideration leads to a better differentiation of the sites conditions. The final representative depths for which the concept designs will be conducted are presented on the following table:

	Gulf of Maine	West of Barra	Golfe de Fos
Design Depth	130m	100m	70m

Table 6: Characteristic depth selected for each site

- Soil conditions: Due to the difficulty to achieve accurate data of the soil conditions without the performance of a geophysical and/or geotechnical campaign (out of the scope of the project), it was decided to establish standard soil profiles for the sites (each one of them different depending on the general characterization of the soil that could be found in open references).

3 Site A: Moderate Environmental Conditions (Reference Location: Golfe de Fos - France)

The primary function of Site A in this project is to allow the evaluation of the different platform concepts in generic, but realistic, conditions of operation with good wind resource and moderate met-ocean extremes. To better the realism of, and the coherence between, the environmental parameters of site A, a real location was selected to define basic site-specific characteristics. For Site A, the selected location is an area some 30-40 km offshore of Fos sur mer, in the Département des bouches du Rhône in the region of Provence-Alpes-Côte d'Azur in Southern France (Figure 9). The procedure for selection of this site is detailed in Section 2.

The area selected for Site A's local information corresponds roughly to Faraman, one of the promising areas identified in the request for expressions of interests for pilot farms of offshore floating wind turbines published by ADEME⁴, the French Energy and Environment Management Agency, in August 2015. An important difference to note is that to ensure a sufficient range of depth was covered between the three sites of the design basis for Lifes50+, mean water depth for Site A is set to be 70 m. This is more shallow than the depth of the Faraman area, which lays roughly offshore of the 100 m isobath. However, it is not expected that this will greatly affect the realism of other environmental parameters for Site A as they are quite generic.

Site conditions presented hereafter should be reasonably representative of this area and in general would provide a basis for a first evaluation of the platforms performance in windy areas with mild



Figure 9: Site A Location

⁴ https://appelsaprojets.ademe.fr/aap/AAP_EolFlo2015-98, last accessed 2015/09/23

met-oceanic conditions. This could include windy areas in the Mediterranean and, although with differences in e.g. wave period or tidal range, the Canary Islands, the Baltic, the South North Sea or the East English Channel.

3.1 Summary of key met-ocean and geotechnical parameters for Site A

In order to allow developers to begin platform design earliest, it was decided to focus initial work for site A on assessing realistic values of a restricted set of met-ocean parameters, based on the information currently available to the project. These parameters are mainly those characterising extreme met-ocean conditions and are oriented towards ultimate limit state design load cases in parked mode. No information is provided herein on parameters necessary for fatigue or power production studies. A more comprehensive assessment of environmental parameters for Site A will be provided in LIFES50+ D7.2 – Design Basis Part A.

Table 7 summarises the values proposed for the basic design parameters. Clearly, they are not of the accuracy and precision that an advanced farm project would necessitate in this area. As stated earlier, the information herein is not a site assessment, rather the motivation for using site-specific information is to ensure sufficient realism of, and coherence between, environmental parameters for Site A.

Summary of assumptions used to derive basic design parameters:

A summary is provided here for convenience, more detailed description of the methods and assumptions can be found in the following sections.

Wind

1. Using U_{10} from building code onshore + 2 m/s
2. Hub height of 120 m above sea level

Notation: DNV-OS-J101 Sec3		Parameter	Value
Wind	EWM (B503)	$U_{10,10m,50-yr}$	28 m/s
		$U_{10,hub,50-yr}$	37 m/s
		$U_{hub,50-yr} = 1.4 \cdot U_{10,hub,50-yr}$	52 m/s
		$U_{hub,1-yr} = 0.8 \cdot U_{hub,50-yr}$	42 m/s
		$\sigma_{U,c} = 0.11 \cdot U_{10,hub}$	4,1 m/s
Waves	ESS (3.3.4.7)	$H_{s,50-yr} ; T_{p,min} - T_{p,max}$	7.5 m ; 8-11 s
		$H_{s,1-yr} ; T_{p,min} - T_{p,max}$	4 m ; 6-11 s
Current	ECS	$V_{c,50-yr}$	0.9 m/s
Water level	MSL		70 m
	EWLR	$HSWL_{50-yr}$	1.13 m
		$LSWL_{50-yr}$	-0.35 m
Soil Conditions		Grain size	50 μm
		Strength	60 kPa at 20 m
		Layer profile	20 m
Others	Water temperature (3.8.3.1)	$T_{max,50-yr}$	30 °C
		$T_{min,50-yr}$	5 °C
	Marine growth DNV-RP-C205 6.7.4.2	Thickness	100 mm
		density	1325 kg/m ³

Table 7: Basic Design Parameters for Site A

3. Wind profile: Frøya (DNV-RP-C205/2.3.2.12). Power law profile with exponent of 0.11 as prescribed by IEC61400-3 (which refers to IEC61400-1) similar.

Waves

1. Significant uncertainty on 50-year H_s due to lack of long record in area. 7.5 m conservative estimate.
2. One-year return level from nearby buoy with safety factor account for different depth.
3. Peak period range based on scatter diagrams of nearby buoys, consistent with model results.

Current

1. Tidal and other non-wind generated currents neglected.
2. Wind generated current as 3% of 1-hour average of 10 m high wind speed.

Water level

1. Mean water depth of 70 m.
2. 50-year return levels from Marseille tide gauge approx. 40 km to the North East.
3. Ignoring sea-level rise (currently approx. 1 mm/year in Mediterranean, vs 3 mm/year globally)

Soil conditions

1. Thick layer of silt assumed as consistent with published result, and to ensure range of conditions covered between the three sites.

Temperature

1. Conservative values based on published results.

Marine growth

1. DNV-RP-C205/6.7.4.2 used as agreed in previous discussions, could underestimate values for the Mediterranean.

3.2 Data sources identified

Environmental parameters values proposed for Site A in the following sections are for the moment based entirely on published results indicated in the reference section – no new analysis of data was carried out. Should the need arise later in the project for additional and more precise site-information, the following data sources may prove valuable.

3.2.1 *In situ* data: closest is 30 km away

Potentially valuable in-situ data available include land met-stations operated by Météo-France. The nearest is Marseille/Marignane (WMO:076500) some 40 km to the North East. Although this station data was not analysed for this study, it may be used at a later date with a measure-correlate-predict approach for northerly winds, for example if precise estimates of energy production are needed. It can be downloaded from the website indicate in [Table 8](#).

A comprehensive list of datasets for marine studies near France is provided by the Système d'information scientifique pour la mer (SISMER)⁵, maintained by IFREMER. Buoy data available in the vicinity include the Candhis buoy data that will be presented in previous sections. Further away from Site A, Météo France and Puertos del Estado maintain deepwater buoys with longer time series, which have not been used in this study but could be for calibration of wave propagation models or in measure-correlate-predict methods (these buoys take wind measurements).

⁵ http://www.ifremer.fr/sismer/FR/banque_nat_FR.htm

N	Source	Data available
1.	<i>SISMER Système d'Information Scientifique pour la MER (maintained by IFREMER)</i> http://www.ifremer.fr/sismer/FR/banque_nat_FR.htm	Overview of marine information, data and datasets and their availability
2.	<i>Candhis buoy network</i> <i>Historical data at</i> http://www.cetmef.equipement.gouv.fr/donnees/candhis/home.php <i>Real time data and summary studies at</i> http://candhis.cetmef.developpement-durable.gouv.fr/	Historical data server is down as of 2015/08/06 and has been so since July, but data obtained upon request to candhis.cetmef@developpement-durable.gouv.fr Real time data and summary studies have been downloaded for the area near golfe de Fos and are available for study
3.	<i>Météo-France buoys.</i> <i>Historical data at</i> https://donneespubliques.meteofrance.fr/?fond=produit&id_produit=95&id_rubrique=32 <i>Real time data at</i> http://www.meteo.shom.fr/real-time/html/lion.html	Closest buoy 100 km away and in deep water but may be used for MCP Historical data available for download as monthly files. Real time data includes graphs of spectra for the last few days.
4.	<i>Meteo-France land station</i> https://donneespubliques.meteofrance.fr/?fond=produit&id_produit=90&id_rubrique=32	Monthly data files (hourly resolution) since 1996 available for station near Fos, including wind speed and gusts. Can be used for MCP for northerly wind, which is probably the most important in the area.
5.	<i>SHOM/GPM de Marseille</i> http://refmar.shom.fr/fr/fos-sur-mer	Real-time Sea-level and tidal data for Fos sur mer harbour Historic data may be available upon request (TBC)
6.	<i>Model data include:</i> <ul style="list-style-type: none">• <i>Highest resolution: ANEMOC</i> http://anemoc.cetmef.developpement-durable.gouv.fr/carte2/• <i>ECMWF reanalysis. ERA-40 is one of the publicly available data set</i> http://apps.ecmwf.int/datasets/• <i>Other possibilities are NCEP, or SIMAR (Spanish Puertos del Estado)</i> http://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx	Long term hindcast available. For use in coastal area, especially near mountainous terrain with orographic winds, reliability should be checked first against in-situ data

Table 8 Summary of relevant data sources identified

There are frequent and regular voluntary observing ship stations in the vicinity with data made available online by Météo-France. The Comprehensive Ocean Atmosphere Dataset (COADS) also would provide long-term ship data in the area. However, for this study focused on extremes, ship observations were not included due to the possibility of bias (less or no navigation is expected in extreme weather).

Long-term sea-level data is available from the tide gauge in the port of Marseille some 40 km to the North East. A survey of published extreme value analyses of this dataset is presented in section 3.

3.2.2 Model data: problematic for local orographic wind (Mistral)

As in-situ data is insufficient to precisely characterize site A, model output must be considered. However, it should be kept in mind that coastal areas are among the difficult places to model accurately, and output from low resolution large-scale models cannot be considered reliable without validation from *in situ* data. Intense orographic wind over complex mountainous terrain, like the Mistral which is central to both design parameters and energy production in the area, are particularly difficult to model.

Outputs in this area from ANEMOC (Atlas Numérique d'États de mer Océaniques et Côtiers, [A1] , a long-term hindcast based on a third generation spectral wave propagation model, are presented in Section 3.3.2.3. ERA-40 6-hourly surface winds and significant wave height are freely available online from ECMWF, but were not used in this study considering their low resolution. However, published analysis of ERA-40 extreme wave heights and winds were compared to the results presented herein (Section 3.3.2.3). NCEP data were not used directly, although ANEMOC uses NCEP winds in the Western Mediterranean to force its wave field.

3.3 Key met-ocean parameters

3.3.1 Site A hub height 50-year wind speed: 37 m/s

3.3.1.1 Insufficient data – using building code prescription

There are no *in situ* wind data at Site A. The Candhis buoys observations in the area do not include wind data. The Météo-France buoy for Golfe du Lion is some 150 km away, and the nearest onshore met-station is 40 km to the north. Regarding model data, as mentioned in Section 3.2.2, lacking site data for their validation they are of uncertain reliability in this coastal area where wind is often dominated by episodes of intense Mistral, an orographic wind carrying cold continental air accelerated as it flows down the Rhône Valley – notoriously difficult to model [A2] .

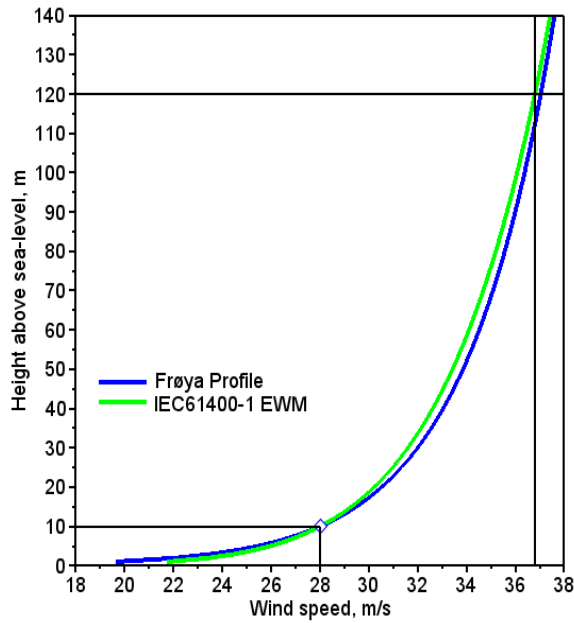
In these conditions it was decided to use building code prescriptions for the coastal area onshore of Site A. There are obvious sources of uncertainty associated with this approach, including low spatial resolution, distance (Site A is some 30 km offshore) and rapid increase in return level of extreme winds when moving offshore. On the other hand, these prescriptions are the reference for large construction projects in this area, and are based on a comprehensive analysis of the available observations in the area, including long time series. No claim is made that this is best possible source of information for extreme winds for Site A, but this is arguably the best source of information among those that were found after substantial search and discussions with partners used to work in this area.

3.3.1.2 At 10-m height from building code: 28 m/s

Reference is made to Eurocode 1 : Actions sur les structures — Partie 1-4 : Actions générales — Actions du vent Annexe nationale à la NF EN 1991-1-4:2005. Figure 4.3(NA) in that document prescribes, for the coastal areas onshore of the considered site, a fundamental value of the basic wind velocity (valeur de base de la vitesse de référence, in French in the document) of

$$u_{b,0} = 26 \text{ m/s} \quad (1)$$

The terminology is different in the building code and in wind turbine standards, but $v_{b,0}$ is defined as the 10-minute mean wind velocity at 10 m above ground, in open terrain with low vegetation, with an



Extreme wind profiles following with DNV-RP-C205 Frøya profile (blue) and EC61400 power law profile (green) for a 10-m, 10-minute mean return level of 28 m/s. (see text for details).

Figure 10: Extreme Wind Profiles

annual probability of exceedance of 0.02. Hence $v_{b,0}$ has identical definition to $u_{10,10,50\text{-yr}}$ in the notation of DNV-OS-J101.

Extrapolating this value offshore is problematic in the absence of information on extreme winds at sea in the area. Noting that increases in the 50-year return level of $u_{10m,10min}$ of up to 2 m/s are commonly observed in the first 10 kilometers offshore (e.g. maps of 50-year wind speeds in [A3] , [A4]), a reasonably conservative value for the 10-m height, 10-minute mean, 50-year wind speed at Site A can be taken as:

$$u_{10m,10min,50\text{ year}} = 28 \text{ m/s} \quad (2)$$

3.3.1.3 Extrapolation to hub height: IEC or DNV profiles

Significant differences in wind speed at hub height can result when using different standard profiles [A3] . The Extreme Wind Speed Model (EWM) in DNV-OS-J101/3/B504 is used herein. The guidance note therein refers to IEC61400-1, of which Clause 6.3.2.1 prescribes the following power-law profile for the 10-minute mean wind speed in the turbulent extreme wind speed model (EWM):

$$u_{50}(z) = v_{ref} \left(\frac{z}{z_{hub}} \right)^{0.11} \quad (3)$$

Where V_{ref} is the reference wind speed at hub height. By definition, V_{ref} must be greater or equal to the 10-minute mean wind speed with a 50-year recurrence period. $V_{50}(z)$ is the 50-year wind speed at height z in the EWM.

On the other hand DNV-OS-J101/3/B303 (guidance note) and DNV-RP-C205/2.3.2.12 recommend the Frøya profile for extreme wind speeds with return periods in excess of 50 years. Although the Frøya profile has a very different expression from Equation (3), for the 50-year wind speed it yields

Height	Wind speed with $u_{10}=28$ m/s	Wind speed with $u_{10}=30$ m/s
10	28	30
30	32	34
50	33	36
100	36	39
120	37	39

50-year return levels of the 10-minute mean wind speed at different heights for Site A, based on a value of 28 m/s at 10 m (column 2, recommended profile). The profile that would result from a more conservative assumption of 30 m/s at 10 m is also indicated for comparison (column 3).

Table 9: Extreme Wind Speed Values for Site A

for Site is very similar to the power law with exponent of 0.11. The wind profiles resulting from these two models are plotted in [Figure 10](#).

The 50-year return level of the 10-minute mean wind speed at hub height (120 m) is thus estimated as

$$u_{\text{hub},10\text{min},50\text{ year}} = 37 \text{ m/s} \quad (4)$$

Values for other heights are indicated in [Table 9](#) (IEC power law profile), together with values that would result from a more conservative assumption for the 10-m height value.

3.3.1.4 Comparison with other estimates

Other standards for civil engineering were consulted. An indicative map provided in European pre-standard ENV 1991-2-4, May 1995, Fig 7.2, suggests reference velocity of 30 m/s in the area considered. Annex A.7 for France in the same document indicates 30.5 m/s for the windiest areas of the Département des Bouches-du-Rhône. The storm wind map provided in British standard BS/EN13000:2004 Cranes – Mobile cranes, Annex N.3 (informative) indicates values of 32 m/s for the coastline onshore of Site A.

These are significantly higher values than the 26 m/s prescribed in Eurocode's National Annex NF EN 1991-1-4:2005. It is assumed that the latter supersedes the other standards, as it is an approved standard to take effect as of 27 March 2008, whereas ENV 1991-2-4, May 1995 provides only non-mandatory technical specifications and the map of storm winds in BS/EN1300:2004 is only an informative annex.

A number of research papers report on extreme value analysis of global or mesoscale model winds. [A5] and [A6] report on extreme value analysis of ERA-40 winds, over Europe and globally respectively. Both suggest slightly lower values for return levels of the 6-hourly fields in the ECMWF winds at 10 m above sea level. However, comparison is difficult due to the low resolution and uncertainty in the representation of storm maximum in the 6-hourly data. In addition as mentioned earlier the strong orographic winds that characterize Site A will be particularly difficult to model, especially with low resolution, large scale models.



The depth of deployment is indicated below the name of the buoy, the next line indicates the central estimate (bold), together with the lower and upper bounds of the 70% confidence interval of the 50-year return level of significant wave height. Note that not all buoys have sufficiently long record to estimate return levels at 50 years (see text for details). Approximate distance from Site A also indicated (orange). Figure adapted from the map of Candhis buoy locations in the vicinity available from CETMEF.

Figure 11: Location of Candhis buoys

3.3.2 Site A 50-year significant wave height: 7.5 m

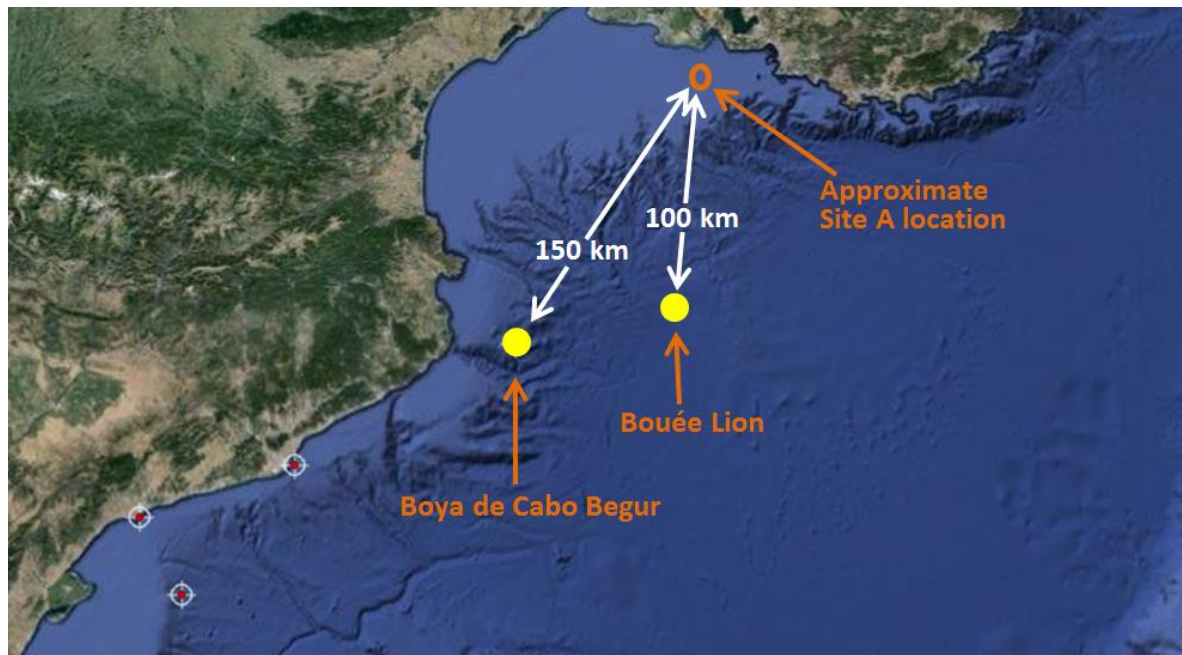
3.3.2.1 Buoy data consistent with a 6.5-7.5 m return level at Site A

The Centre d'études techniques maritimes et fluviales (CETMEF) operates the Centre d'archivage national de données de houle in situ (Candhis) [A3], which includes a number of buoys in the vicinity of Site A. The location of nearby Candhis buoys is indicated in Figure 11.

Summary reports including extreme value analysis of sea-states observed at the buoys can be downloaded from the Candhis website. As well, CETMEF has provided LIFES50+ with some times series of oceanographic data from these buoys, but they cannot be analysed in time for this report and will be used at a later date for the more advanced design specification. For those buoys for which summary reports include an extreme value analysis of sea-states, the corresponding estimates of 50-year return levels (central and 70% confidence interval) are indicated in Figure 11, below the buoy location.

It should be noted that only the two stations near Sète (on the left side) have a sufficiently long record to estimate return levels at 50 years with some reliability (as a rule of thumb extrapolation of return levels is considered valid at return periods up to 5 times the observed record length). The closest station for which extreme values are provided by CETMEF, Camargue, is some 30 km away from the area considered for Site A, but only has a 3 years effective record length. In addition all these measurements are taken in significantly more shallow water than Site A.

Nonetheless, they are arguably the best available *in situ* observation available in the area. Ideally these would be used to fit a high resolution wave propagation model but this is beyond the scope of the project, where site-specific information is just to be used to define sufficiently realistic conditions for evaluating different concepts of floating platforms.



Approximate location and approximate distances of the buoy of Cabo Begur, bouée golfe du lion and site A. Boia Cabo Begur is moored in 1200 m depth. Figure adapted from Puertos del Estado's website.

Figure 12: Long-term, deepwater buoy locations

Bearing in mind these limitations, what can be concluded is that the record of observations in the area is not inconsistent with a 50-year return level of H_s in Site A of some 6.5-7.5 m. A conservative (though still uncertain) return level at 50 years for significant wave height at Site A is thus proposed as

$$H_{s,50y} = 7.5 \text{ m} \quad (5)$$

However, for a research project which at this stage does not represent any risk to life, property or the environment, a less conservative value of 7 m for $H_{s,50y}$ at Site A would also be acceptable and well within the uncertainty given the lack of site observation. The choice is left to a consensus decision between developers and other partners.

3.3.2.2 Other buoy data too distant from Site A

Of the data sources that were identified, the closest deepwater long-term buoy records are those from the buoys operated by OPPE (Boia Cabo Begur) and by Météo France (bouée golfe du Lion). They are situated respectively some 150 and 100 km away from the site considered (Figure 12). In addition, mesoscale modelling shows [A7] [A8] significantly higher return levels in this area (typically about 1 m larger than those offshore of Fos sur mer). They are thus hardly representative of conditions in Site A.

The analysis of extreme values in a record of over 14 years at Boia Cabo Begur yields a return level at 50 years for the significant wave height of 8.3 m [A9]. This can be viewed as a very conservative upper bound for Site A.

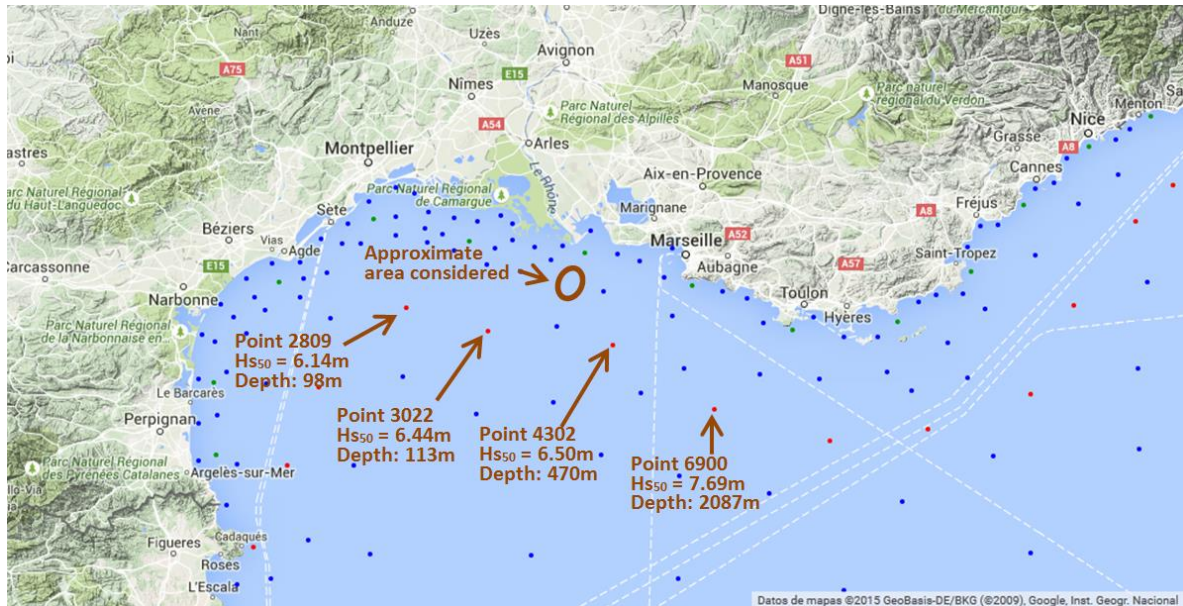
3.3.2.3 Model outputs overall consistent with $A H_{s50} = 7.5$ m at Site A

Modelling of extreme waves is more difficult than the mean regime, and by definition, cannot be validated with many independent observations. Priority was thus given to information based on *in situ* observations despite the limitations discussed earlier. Model results are nonetheless presented for comparison.

As discussed in Section 3.2.2, the highest resolution model outputs available for this area are those in the ANEMOC database [A1]. The output is available online at <http://anemoc.cetmef.developpement-durable.gouv.fr/carte2/> (last accessed 2015/09/16). For the Mediterranean, it is a 30-years hindcast (1979-2008), with NCEP2 winds forcing TOMAWAC, a third generation spectral wave propagation model. Results of the extreme value analysis of four data points in the area are available free of charge. Their location and corresponding values for the 50 years significant wave height are depicted in Figure 13.

These output points are significantly offshore from Site A, the closest being some 40 km to the South. As expected, there is a significant increase in return level between the most shallow one, with $H_{s,50y} = 6.1$ m at 98 m depth, to $H_{s,50y} = 7.7$ m at over 2000 m depth. Overall, the ANEMOC record is thus not inconsistent with the conservative value of $H_{s,50y}$ of 7.5 m for Site A that was chosen based on the Candhis buoys record.

[A8] reports on mesoscale modelling results showing the variability of $H_{s,50y}$ in the Western Mediterranean. Values for Site A appear significantly lower, of the order of 5.5-6 m, but this work is not focused on the area around Site A, which is at the very edge of the model domain. [A6] analyzed ERA-40 global model output, Site A is between lines of return level at 100 years of 8.4 and 12 m, but the spatial variability of $H_{s,50}$ in the region [A8] suggests that it would be at the lower end of this interval. The 50-year return level would typically be some 5-10 % lower than the 100 year return level, depending on the shape of the distribution. Hence, this analysis of ERA-40 data yields results that also are not inconsistent with a return level at 50 years for Site A of 7.5 m.



Location of ANEMOC database output points in the area. Indicated below the output point number are the values of Hs 50 years return level and the depth of the output point. Figure adapted from the ANEMOC web interface.

Figure 13: ANEMOC output points

3.3.3 Peak period range for 50-year sea-state: at least 8-11 s

Scatter diagrams of data collected by Candhis buoys in the area (Section 3.3.2.1) show that the largest significant heights are associated with peak periods between 8 and 11 seconds, with no observation reported outside of this range. Similar values are reported [A9] for the Boya Cabo Begur further away and in deep water. ANEMOC model outputs reported for the data points presented in Section 3.3.2.3 show similar results, albeit slightly longer periods than the Candhis buoy data, as is expected from their deeper locations.

It is thus proposed that the extreme sea states (ESS) for the design load cases for Site A cover at least the following range of peak period:

$$8 \text{ s} \leq T_p \leq 11 \text{ s} \quad (6)$$

Bearing mind, however, that no study has been found of the extreme long (or short) wave periods during storms in this area, and that both DNV-OS-J101 and IEC61400-3 prescribe that in the absence of information indicating otherwise, the wave period resulting in the highest loads be used in the design load cases, it is left to developer's engineering experience to decide on which extreme wave period to use – but it should at least include the range in equation (6).

3.3.4 50-year current speed: wind-generated, 90 cm/s

Tidal currents are small in the Mediterranean, and not being a hazard for navigation they are not included the comprehensive maps of tidal currents that are otherwise available for the French littoral⁶. Close to the mouth of the Rhône river discharge and/or salinity gradients may be important at certain times, but are probably small at the distance and depth of site A. For the same reason wave-driven currents (e.g. rip currents) can be safely neglected. Further offshore along the continental slope a strong (up to 50 cm/s) geostrophic current can be encountered [A10] but it is rather narrow and is expected in significantly deeper water and is unlikely to have a strong influence in the range of depth of Site A.

Currents in this area can thus be safely assumed to be dominated by the wind-driven component. IEC61400-3/6.4.2.2, Equation 15, prescribes a wind generated sea surface current velocity that in the absence of information indicating otherwise, may be estimated as 1% of the 1-hour mean of the 10 m wind speed. DNV-OS-J101/3/D303 and DNV-RP-C205/4.1.4.4 recommend significantly higher values of 1.5-3% of the 1-hour mean, 10-m wind speed. Usual practice in oceanography [A11] is more in the range of the latter, at least for wind speeds up to 30 m/s. 3% is adopted here as a probably conservative value. It should be noted that in certain areas, still higher values (up to 4% of U10) are reported for the wind driven current, but it is rare and at this point in the project there is no reason to take values beyond the upper-end of the more conservative standard.

With the Frøya profile in DNV-OS-J101/3B/303 and DNV-RP-C205/2.3.2.12, at 10 meters height the 1-hour mean is 0.91 times the 10-minute mean. Using the 50-year wind speed from Section 3.3.1.2, the 1 hour mean speed is obtained from the 10-minute mean as follows:

$$\begin{aligned} u_{10m,1hour,50year} &= 0.91 u_{10m,10minutes,50year} \\ &= 25.5 \text{ m/s} \end{aligned} \quad (7)$$

The 50-year return level of the wind-generated current at the surface is then evaluated as

$$\begin{aligned} v_{c,wind}(0) &= 0.03 \times u_{10m,1hour,50year} \\ &= 0.77 \text{ m/s} \end{aligned} \quad (8)$$

To account for a possible small but non-zero contribution from geostrophic currents, tides or river discharge, and in the absence of further information it is proposed to set the (likely quite conservative) value of the 50-year current speed for Site A as:

$$v_{c,50 \text{ years}}(0) = 90 \text{ cm/s} \quad (9)$$

For a research project that at this stage doesn't entail risk to life, property or the environment, 80 cm/s may also be an acceptable value for $v_{c,50 \text{ years}}$ in view of the information available. This decision is left to the consensus of developers and other Lifes50+ partners.

⁶ See SHOM: <http://www.shom.fr/les-produits/produits-nautiques/maree-courants-de-maree/atlas-de-courants-de-maree/>

3.3.5 50-year high and low water levels: +1.13 and -0.35 m

Except for a few bays and inlets, tidal range is small in the Mediterranean, typically of order 40 cm, including for the Site A area (e.g.[A12]). Variations in sea level are thus dominated by atmospheric effects.

The tide gauge from the port of Marseille, some 40 km to the North East, offers an excellent long-term record to assess return level of storm surges. Water level extremes at this port are assumed to provide an adequate estimate of the range for Site A.

Table 10 summarises results of extreme value analyses reported in [A13] [A14] [A15] [A16] . Results differ due to the different methods and assumptions employed, such as choice of distribution, correction for long-term trends such as sea-level rise, treatment of joint probability distribution or adjusting for long-term changes in reference level. In addition some of these reports do not focus on providing return level estimates at this point in time but rather on its changes over long periods. Reference is made to these reports for further details.

For the extreme high water level, it is proposed to use the results from CETMEF as the commonly referred-to authority for the dimensioning of coastal infrastructure in this area. The extreme high water level with a 50-year return period, referenced to Site A mean water depth (70 m), is thus proposed as:

$$\text{EHWL} = 1.13 \text{ m} \quad (10)$$

In general extreme high water levels have received more attention than low water levels, as extreme highs are far more critical for flooding hazards and coastal infrastructure planning. Although not the ideal approach due the different methods and reference level they use, the high water level from CETMEF, arguably the most established reference, is combined with the extreme water level range from [18], i.e. 145+3 cm, as it is the only study that includes an estimate for extreme low water level. The extreme low water level with 50 years return period, referenced to the mean water depth at Site A depth (70 m), is thus proposed as:

$$\begin{aligned} \text{ELWL} &= 1.13 - (1.45 + 0.03) \\ &= -0.35 \text{ m} \end{aligned} \quad (11)$$

Sea-level rise is not explicitly considered here, although certain of the studies in **Table 10** have corrected their water level range with long-term trends including sea-level rise. In general observed sea-level rise in the Mediterranean has been slower than the global average (resp. about 1 mm/year vs. 3 mm/year).

Author	Data	Method	50-year high, cm	50-year low, cm
CETMEF	1985-2011	Exponential law	113	n.a
		Generalised Pareto	104	n.a
Letetrel et al.	1885-2008	Generalised Pareto	120	n.a
Gaufres et al.	1885-2003	Jenkinson law	100	n.a
Pirazolli	1985-86, 1998-2004	Joint probabilities, GEV	145	-3

Extreme water levels reported in different studies of the data record at the port of Marseille. Except for CETMEF, the values are read off the published graphs and are less precise. See text for references and details.

Table 10: Extreme water levels at Marseille



3.3.6 High and low water temperature: 5-30 °C

Water temperature in Site A is not expected to govern design for any of the concepts, so the search for accurate statistics has not been prioritized in this study. Little information on water temperature extremes in the area has been found at time of writing, so only an extremely conservative range can be provided at this point. This can be refined at a later date if it turns out to be an important parameter.

The coldest water mass in the area, the Western Mediterranean Deep Water has temperature between 12.75 and 12.80 °C [A17] [A18] . However, [A18] reports that cold, continental freshwater discharged by the Rhône combined with winter cooling being applied only to a thin surface layer can lead to sea surface temperatures below 8 °C in February. No report of lower temperature has been found at time of writing. A (perhaps conservative) value of 5 °C is chosen as the extreme low water temperature.

The lowest daily mean air temperature, as applies to structures above the lowest waterline (DNV-OS-J101/6/A200) is proposed to be the record low temperature reported⁷ for Marseille of -16.8 °C. As it will not be the lowest daily mean temperature of the three sites, no further precision is sought here.

Regarding extreme high water temperature, although sea surface temperature over 26 °C are common in summer south of the Pyrenean, the area near Golfe de Fos is usually significantly colder. Nonetheless, to account for the possible warming a thinly mixed surface layer in summer, a conservative maximum value of 30 °C is proposed here.

This range of temperature is in all likelihood quite conservative, and could be refined at a later stage should there be need for more precise evaluation.

3.3.7 Geology information: assuming thick layer of silt

Sediment discharge from the Rhône is expected to characterize soil conditions in this area. The sediment bed in the area of Site A has a high fraction of mud (silt and clay) [A19] , although some areas of coarse sand are also found in the vicinity [A10] .

To ensure an adequate spectrum of soil conditions is covered between the three sites, the soil at Site A is set to be composed of an upper layer of dense sand, a medium layer of soft clay, and a lower layer of stiff clay. The characteristics of this generic model are provided in Figure 68 at the end of this report.

3.3.8 Marine growth

As agreed in discussions in WP1 and WP7, DNV-RP-C205/6.7.4.2 is used to estimate marine growth. For the case of Site A, density is thus set to 1325 kg/m³ and thickness to 100 mm from 2 m above sea level to 40 m depth, and 50 mm thickness below 40 m depth. However, it should be noted that DNV-RP-C205/6.7.4.2 recommends to use the table only North of 56°. As these figures could thus underestimate growth in the Mediterranean, they may be refined at a later date.

⁷ See e.g. <http://www.infoclimat.fr/climatologie-07650-marseille-marignane.html>. Record set in February 1956.

4 Site B: Medium Environmental Conditions (Reference Location: Gulf of Maine - US)

This location has been selected to open the project to the incipient market of the renewables energies in the United States. Within the site selection process, this site was considered and selected as a “moderate site” in regard to the met-ocean conditions severity characterization.

4.1 Location

Gulf of Maine site is intended to be located at North Atlantic Ocean, about 25 km southwest of Monhegan Island and 65 km east of Portland. The central point of the proposed site is placed at [43°33'22.4"N 69°27'08.7"W](#)).

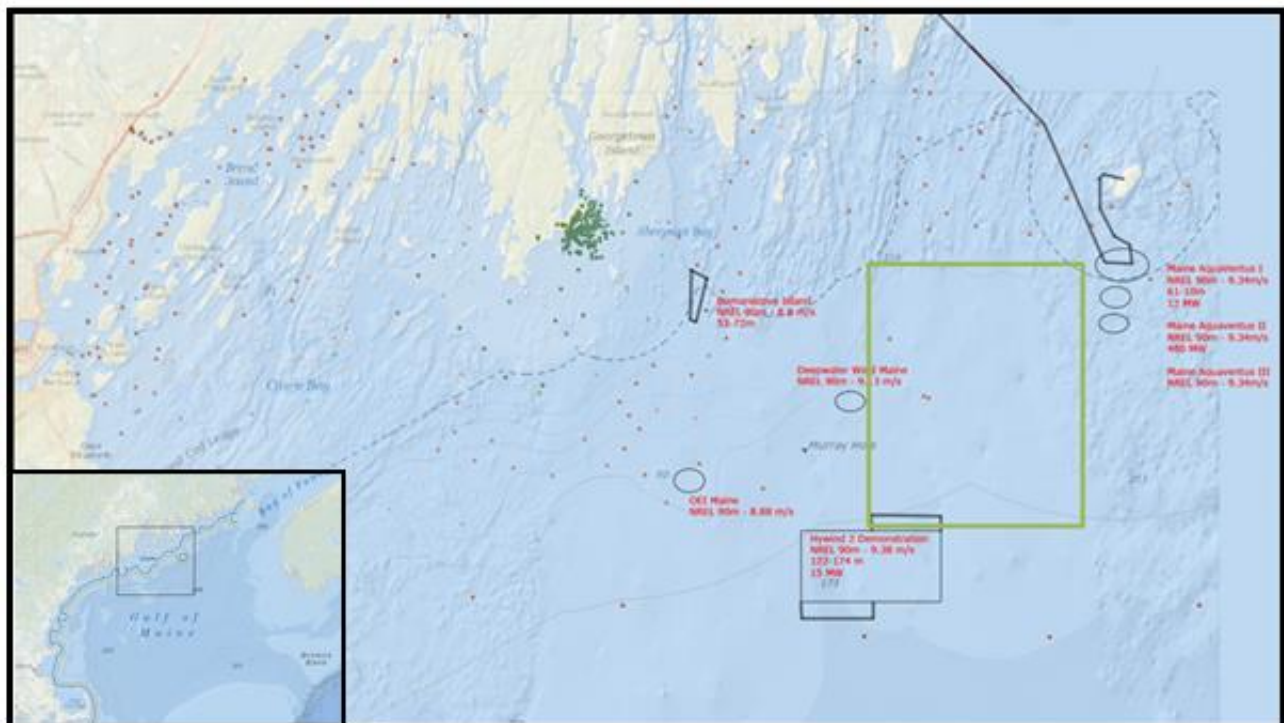


Figure 14: Gulf of Maine site location

4.2 Sources of Information

Close to the site, there are mainly three different measurement buoys that are taken as reference for the site characterization. The location of each of the buoys is shown in the map below:

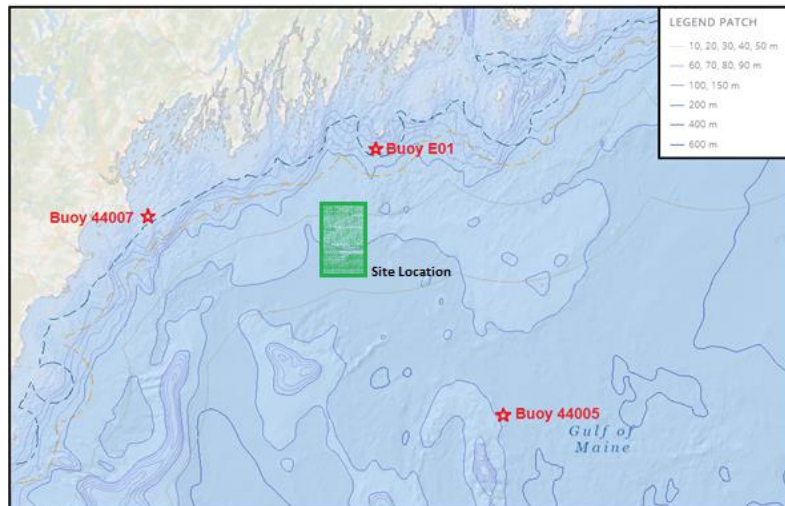


Figure 15: Reference buoys' position

Buoy E01 is the closest to the selected area and, because of this proximity, was selected as the main source of information. General characteristics of this buoy are:

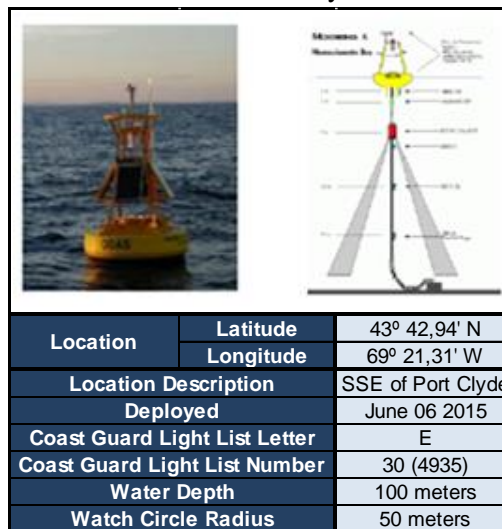


Figure 16: Main characteristics of buoy E01

Data available at this buoy is obtained from reference [B1] for:

- Wave climate: Raw data of significant wave height and wave period. This data is provided in half-hour periods.
- Wind climate: 10-minute values of mean wind speed, wind direction and wind gust.
- Currents characteristics: Mean value for the hourly surface current speed and its associated direction.
- Other environmental characteristics: Such as water temperature, salinity and density, air temperature.

4.3 Water Depth and Water Levels

4.3.1 Bathymetry

The figure below presents a piece of the NOAA reference map taken from [B2] , which shows the bathymetry contours of the Gulf of Maine selected site.

The area has a mean depth of 130 m with a maximum depth towards South of 150 m and a minimum depth of 100 m at the North (towards the coastline). The area is located in the plateau of the continental shelf, hence seabed is fairly flat all over the site with a very gentle slope deepen from North to South that can only be appreciated by means of the bathymetry contour lines given in the figure below.

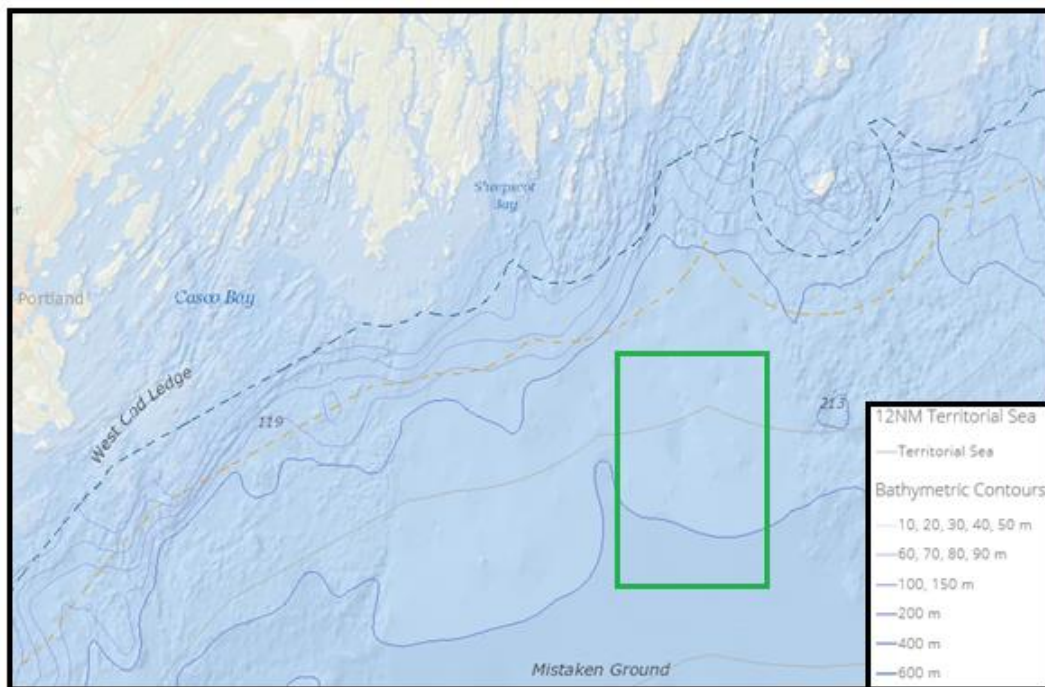


Figure 17: Gulf of Maine bathymetry

4.3.2 Water Levels

Sea water levels were obtained from reference [B3] . These are tidal statistics obtained for Rockland and based on NOAA National Ocean Service benchmark tables [B2]. These values have been also checked with data from UMOOS (Reference [B4]):

		Rockland (8415490)
Highest Observed Water Level	[m]	4,32
Highest Astronomical Tide (HAT)	[m]	3,22
Mean High Water (MHW)	[m]	3,10
Mean Sea Level (MSL)	[m]	1,62
Mean Tide Level (MTL)	[m]	1,61
Mean Low Water (MLW)	[m]	0,12
Lowest astronomical tide (LAT)	[m]	0,00
Lowest Observed Water Level	[m]	-0,80

Table 11: GoM characteristic water levels

4.4 Wind Climate

Wind climate characteristics are obtained from buoy E01 [B1] through the raw data measured since 2003 (up to July 2015). Although this information is very detailed regarding to the wind speed characteristics (mean wind speed, direction and wind gust) in 10-minutes time periods, only information at the anemometer height is available (4 meters above sea level), and the wind speed at other different heights shall be estimated using a standard wind profile.

4.4.1 Wind Shear Profile

4.4.1.1 Operational Conditions' Profile

In order to select the most accurate profile for the extrapolation of the wind speed at different heights, the two profiles proposed by DNV-OS-J101 [B5] have been checked and compared with the reference data taken from the Wind Speed NREL maps [B6] that provide average speeds at different heights.

- The power law profile: Used accordingly to the recommendations stated in DNV-OS-J101 [B5] Sec3, 3.2.4.6.

$$u_{10}(z) = u_{10}(z_0) \left(\frac{z}{z_0} \right)^\alpha$$

An exponent of $\alpha = 0.14$ will be considered, following the guidance note stated in DNV-OS-J101 [B5] Sec 3, 3.2.5.9.

- The logarithmic profile: Reference is made to DNV-OS-J101 [B5] Sec3, 3.2.4.6.

$$u_{10}(z) = u_{10}(H) \frac{\ln \left(\frac{z}{z_0} \right)}{\ln \left(\frac{H}{z_0} \right)}$$

Where H is the reference height and roughness parameter is estimated as the most conservative proposed by DNV OS-C205 [B7] $z_0 = 0,0002$.

Next table summarizes the different wind profiles obtained using the assumptions stated above regarding to the wind profile for the annual average wind speed (see Section 4.4.2.3 for average wind speed considerations).

Normal Wind Profile			
Height [m]	Speed [m/s]		
	NREL	Potential Profile	Logarithmic Profile
4	-	6,4	6,4
5	-	6,7	6,5
10	7,0	7,3	6,9
20	-	8,1	7,4
50	8,0-8,8	9,2	8,0
80	9,0	9,7	8,4
90	9,0-9,5	9,8	8,5
100	-	10,2	8,5
119	-	10,5	8,7

Table 12: Proposed profiles comparison table

From this data, it is selected the “**0,14 Potential Profile**” as the most adequate for the Gulf of Maine site 10-minutes wind speeds calculation at operational conditions and at different heights, being the resulting wind speed profile more conservative. The table below remarks this selected wind profile:

Normal Wind Profile	
Height	Speed
[m]	[m/s]
4	6,44
5	6,65
10	7,34
20	8,10
50	9,24
100	10,20
119	10,46

Table 13: Operational conditions wind speed profile

4.4.1.2 Extreme Conditions' Profile

In extreme conditions, as in case of the “normal wind profile” (section 4.4.1.1), a potential profile is used. However, in this case, and following the recommendation of DNV and ABS, the most appropriate potential profile to be used is the “**0,11 Potential Profile**” instead of the “0,14 Potential Profile”.

$$u_{10}(z) = u_{10}(H) \left(\frac{z}{H} \right)^{0.11}$$

Therefore, the resulting extreme wind speeds at different heights, taking into account the 50-year reference wind speed at 4 meters height (taken from section 0), is:

Extreme Wind Profile	
Height	Speed
[m]	[m/s]
4	30,3
5	31,0
10	33,5
20	36,1
50	40,0
100	43,1
119 ⁸	44,0

Table 14: Extreme wind speed profile

4.4.2 Wind Speed Distribution

4.4.2.1 Percentage frequency distribution

The following table summarizes the occurrence probability of the different ranges of mean wind speed taken in form of the raw data from buoy E01 [B1] . Wind speeds are registered in 10-minute periods at a height of 4 meters.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual
Wind Speed [m/s]	<1	1,0%	1,5%	1,9%	3,2%	3,7%	4,6%	5,8%	5,3%	3,8%	1,7%	1,3%	0,9%	2,9%
	1< U _{10-min} <2	2,1%	3,3%	4,3%	8,4%	11,7%	14,9%	15,2%	15,4%	11,4%	4,9%	4,6%	2,7%	8,2%
	2< U _{10-min} <3	4,3%	5,0%	6,8%	10,8%	15,8%	19,7%	21,3%	21,8%	15,6%	8,5%	6,4%	4,3%	11,7%
	3< U _{10-min} <4	5,7%	6,0%	9,2%	12,2%	15,1%	18,5%	19,4%	18,8%	15,9%	10,3%	7,4%	6,0%	12,1%
	4< U _{10-min} <5	7,7%	7,6%	8,8%	11,8%	12,0%	14,5%	15,1%	15,0%	14,2%	12,3%	9,0%	6,8%	11,2%
	5< U _{10-min} <6	9,1%	9,9%	9,7%	11,6%	10,5%	9,4%	10,0%	10,0%	13,0%	13,1%	10,2%	8,0%	10,4%
	6< U _{10-min} <7	9,8%	10,3%	11,1%	10,3%	8,9%	6,6%	6,7%	6,5%	10,2%	11,0%	11,2%	10,2%	9,4%
	7< U _{10-min} <8	11,3%	10,5%	11,4%	9,4%	7,8%	4,8%	3,5%	3,4%	7,1%	11,0%	12,2%	11,9%	8,7%
	8< U _{10-min} <9	12,0%	9,7%	10,2%	7,5%	5,5%	3,2%	1,9%	2,0%	4,9%	9,1%	11,5%	10,8%	7,4%
	9< U _{10-min} <10	12,1%	10,1%	9,4%	4,8%	3,5%	2,0%	0,7%	0,6%	2,4%	6,8%	10,0%	10,8%	6,1%
	10< U _{10-min} <11	8,7%	8,7%	7,3%	4,1%	2,8%	0,8%	0,3%	0,3%	1,0%	4,1%	6,9%	9,4%	4,5%
	11< U _{10-min} <12	6,7%	6,7%	4,7%	3,1%	1,5%	0,6%	0,2%	0,3%	0,3%	2,7%	4,1%	7,4%	3,2%
	12< U _{10-min} <13	4,0%	4,8%	2,3%	1,5%	0,6%	0,2%	0,0%	0,2%	0,2%	1,6%	2,6%	4,1%	1,8%
	13< U _{10-min} <14	2,7%	3,2%	1,5%	0,6%	0,4%	0,0%	0,0%	0,2%	0,1%	1,0%	1,3%	3,3%	1,2%
	14< U _{10-min} <15	1,5%	1,4%	0,9%	0,4%	0,2%	0,0%	0,0%	0,2%	0,0%	0,8%	0,7%	1,7%	0,7%
	15< U _{10-min} <16	0,9%	0,7%	0,3%	0,1%	0,1%	0,0%	0,0%	0,0%	0,0%	0,5%	0,4%	1,0%	0,3%
	16< U _{10-min} <17	0,2%	0,3%	0,1%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%	0,3%	0,2%	0,3%	0,1%
	17< U _{10-min} <18	0,2%	0,2%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,1%	0,1%	0,1%	0,1%
	18< U _{10-min} <19	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	19< U _{10-min} <20	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	20< U _{10-min} <21	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
	U _{10-min} >21	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Table 15: Wind speed distribution at E01 [B1] buoy at 4 m height

⁸ It is worth to remember that this value of the wind speed at 119 meters height with a return period of 50 years is also known as v_{ref} .

4.4.2.2 Weibull distribution parameters

According to DNV OS-C205 [B7] , Sec 2.3.1.2, unless data indicate otherwise, a Weibull distribution can be assumed for the arbitrary 10-minute mean wind speed U_{10} in a given height z above the ground or above the sea water level. Therefore, a Weibull distribution has been selected to represent the long-term probability distributions of the wind speed.

$$F_{u10}(u) = 1 - \exp\left(-\frac{u - \delta}{A}\right)^k$$

Weibull coefficients fitting the percentage frequency distribution presented in the previous section are:

Weibull Parameters	
Scale coefficient (A)	6.214
Shape coefficient (k)	1.701
Location coefficient (δ)	0.000
R^2	0.986

Table 16: Weibull distribution parameters

Figure 18 shows the comparison between the original raw data distribution (blue) and the distribution obtained from the associated Weibull (red) from the table above (on the left the occurrence probability and on the right the cumulated probability). The level of accuracy obtained with the fitting is considerably good.

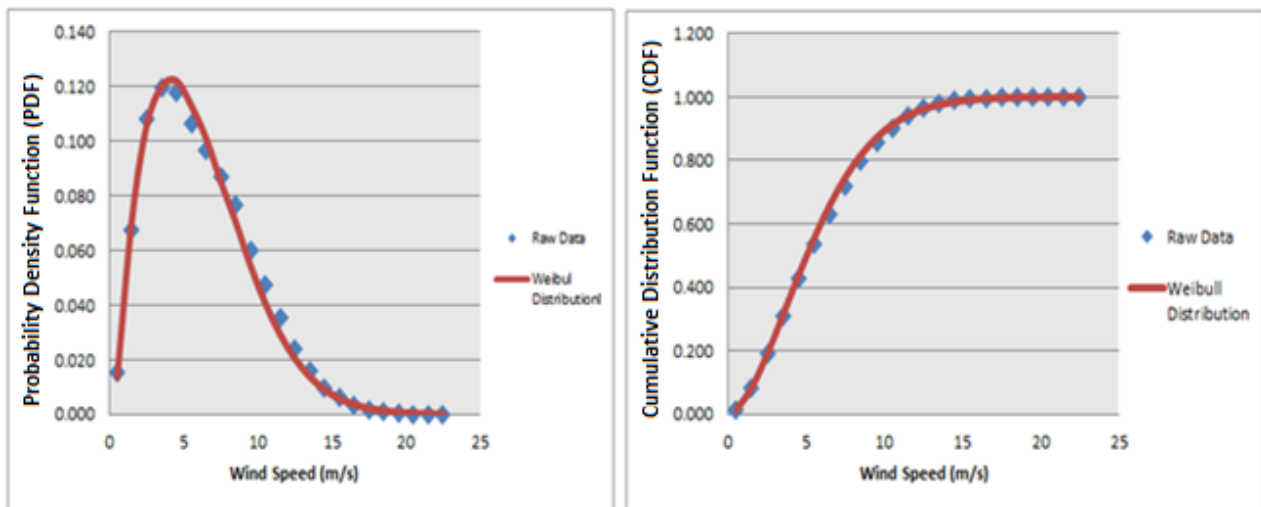


Figure 18: Raw data and Weibull distribution correlation

4.4.2.3 Annual Average Wind Speed

The IEC 61400-1 [B8] defines the “annual average” wind speed as the mean value of a set of measured data of sufficient size and duration to be considered as a representative set of the certain site under study. Based on that definition:

	Year	Average speed [m/s]
Annual average wind speed	2003	6.29
	2004	7.11
	2005	6.28
	2006	7.76
	2007	5.59
	2008	6.74
	2009	6.74
	2010	6.09
	2011	6.08
	2012	5.63
	2013	5.95
	2014	6.09
	2015	7.30
Total		6.44

Table 17: Annual average wind speed

The annual average wind speed at 4m of height (reference height where the data of the buoy E01 [B1] is given) for Gulf of Maine site is 6,44 m/s. At a 10 m height, which is normally the height used as reference, this annual average wind speed has a value of **7,34 m/s**. (using the normal wind profile defined in section 4.4.1.1 for the height extrapolation).

Annual average wind speed at hub height (119m above MSL), using the Potential Profile with a coefficient $\alpha=0,14$:

U (119m)	Average Wind Speed [m/s]
	10,02

Table 18: Annual average wind speed at hub height

4.4.2.4 10-min Reference Wind Speed (1, 5, 10 and 50 years return period)

These values are calculated from the Weibull Distribution defining parameters given in Section 4.4.2.2.

	Return Period [years]	Wind Speed [m/s]
U (4 m)	50	30,3
	10	28,3
	5	27,4
	1	25,3

Table 19: Reference wind speeds at 4 m height

If using the 0,11 potential profile to extrapolate these values to the hub height (taken as 119 m above MSL), the resulting wind speeds are:

U (119m)	Return Period [years]	Wind Speed [m/s]
	50	44.0
	10	41.1
	5	39.8
	1	36.7

Table 20: Reference wind speeds at hub height

4.4.3 Wind Direction

This section summarizes the information gathered by the NOAA buoy E01 [B1] from January-2003 to June-2015 regarding the wind climate direction. It is worth to notice that all the information given is referred to wind characteristics at the anemometer height (4 meters above sea level).

4.4.3.1 Wind Rose

The probability of occurrence associated to the different wind directions is given below as from the data registered in buoy EO1, referred to a reference height of 4m.

Wind Direction [%] ⁹	0	6,1
	22,5	5,4
	45	5,1
	67,5	4,5
	90	3,4
	112,5	3,2
	135	3,4
	157,5	4,6
	180	7,2
	202,5	10,2
	225	9,5
	247,5	7,6
	270	6,7
	292,5	7,6
	315	8,7
	337,5	6,9

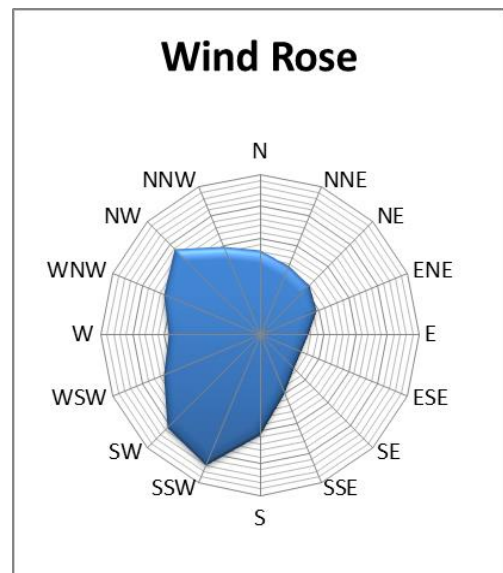


Table 21: GoM wind rose

⁹ Considered bin size: 22,5°

4.4.3.2 Scattergrams of ten minutes average wind speed

Obtained from raw data treatment of buoy E01 [B1] at 4m height.

		Wind Direction [°] ¹⁰															
		0	22,5	45	67,5	90	112,5	135	157,5	180	202,5	225	247,5	270	292,5	315	337,5
Mean Wind Speed [m/s]	$u_{10} < 1$	409	360	354	352	390	321	412	445	424	461	494	503	465	396	430	411
	$1 < u_{10} < 2$	1559	1392	1373	1425	1418	1483	1619	1939	2300	2393	2555	2395	2068	1880	1599	1576
	$2 < u_{10} < 3$	2305	1758	1853	2160	2176	2380	2751	3288	4029	4618	4328	4043	3426	2800	2349	2232
	$3 < u_{10} < 4$	2428	2060	2160	2399	2131	2058	2230	3033	4589	6059	5617	4737	3818	3137	2543	2488
	$4 < u_{10} < 5$	2516	2403	2347	2434	1725	1689	1845	2689	4391	6161	6186	4427	3503	3123	2640	2653
	$5 < u_{10} < 6$	2598	2381	2449	2201	1370	1155	1338	2018	3879	5762	5545	3853	2794	2856	2918	2697
	$6 < u_{10} < 7$	2486	2541	2115	1921	1191	1039	1204	1703	3128	5026	4488	2985	2482	2855	3433	2850
	$7 < u_{10} < 8$	2605	2438	1991	1622	1025	798	907	1315	2463	4127	3688	2205	2197	2700	3930	3344
	$8 < u_{10} < 9$	2416	2278	1838	1313	810	745	690	1061	2032	3295	2779	1929	1921	2441	4123	3298
	$9 < u_{10} < 10$	1796	1757	1333	940	687	526	451	842	1388	2145	1875	1672	1448	2477	3945	2621
	$10 < u_{10} < 11$	1400	1125	1069	653	539	427	347	523	940	1644	1365	1256	1394	2387	3425	1893
	$11 < u_{10} < 12$	1100	833	890	507	381	381	335	369	630	1045	817	907	1196	1904	2554	1414
	$12 < u_{10} < 13$	890	681	684	384	300	245	262	212	400	582	502	621	761	1284	1606	835
	$13 < u_{10} < 14$	726	503	494	249	221	171	172	154	182	257	240	412	505	948	944	560
	$14 < u_{10} < 15$	423	267	317	220	207	129	106	96	90	199	131	242	286	561	512	294
	$15 < u_{10} < 16$	274	174	217	179	110	50	69	55	38	92	53	165	191	425	297	153
	$16 < u_{10} < 17$	160	131	114	130	51	43	31	25	18	35	34	67	82	187	139	105
	$17 < u_{10} < 18$	108	106	68	27	15	53	16	4	18	9	14	26	38	86	54	75
	$18 < u_{10} < 19$	31	37	33	45	3	21	4	1	3	10	12	8	18	49	29	47
	$19 < u_{10} < 20$	11	28	11	20	1	1				5	3	5	21	8	10	15
	$20 < u_{10} < 21$	4	16	2	9		1					2	4	14	4	9	6
	$21 < u_{10} < 22$	1	8		1							1	2	4	1	1	6
	$u_{10} > 22$												4				1

Table 22: Wind speed/direction scatter diagram

¹⁰ Considered bin size: 22,5°

4.4.4 Turbulence Intensity

Turbulence intensity is defined for a certain wind speed as the ratio between the standard deviation of that speed and the 10-minute averaged wind speed. However, there is no information regarding the standard deviation of the wind speed in the raw data measured, neither in the reference buoy E01 [B1] nor in the other buoys near the selected site (NOAA buoys 44005 and 44007).

Therefore, it is proposed to use IEC 61400-1 [B8] Wind Turbine Classes to obtain a reference value for the turbulence intensity. Wind Turbine Classes are defined in terms of wind speed and turbulence parameters. The values of wind speed and turbulence parameters are intended to represent many different sites and do not give a precise representation of any specific site, but guarantee that a Wind Turbine designed for a certain class can be installed on sites with wind conditions equal or less severe to the ones that define the specific class itself.

Wind turbine class	I	II	III	S
V_{ref} (m/s)	50	42,5	37,5	Values specified by the designer
A I_{ref} (-)	0,16			
B I_{ref} (-)	0,14			
C I_{ref} (-)	0,12			

Figure 19: IEC 61400-1 [B8] reference table for I_{ref}

According to the reference wind speed at site ($v_{ref}=v_{50years,hubheight}=44m/s$) and standard values of turbulence intensity on similar sites (see [B8]), wind turbine class is assumed to be IC, and therefore I_{ref} , defined as the expected value of the turbulence intensity at 15 m/s would be assumed 0,12.

Class	I_{ref}
IC	0.12

If the turbulence intensity is required for other values, following table can be used:

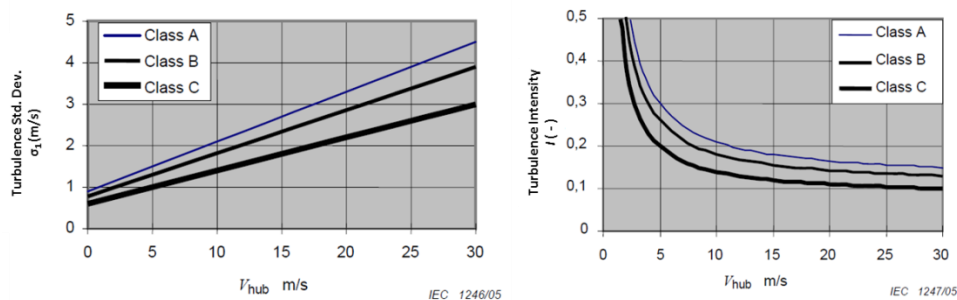


Figure 20: Turbulence Intensity for different Wind Turbine Classes, as defined in IEC 61400-1 [B8]

4.4.5 Spectral Density

As part of the environmental characterization of the wind climate in the selected site, an adequate model which properly represents the wind energy over frequencies (spectral density) shall be defined.

In this case, on the base of the recommendations provided in [B5] and since information available at site is not sufficiently detailed, the Kaimal¹¹ model has been considered as the most suitable for characterizing the wind spectral density.

4.4.6 Wind Gust Characteristics

As it was done for the wind data in relation to mean wind speed, the data available for the wind gust is obtained from NERACOOS buoy E01 [B1] (see in section 4.2) and processed to obtain its characteristic occurrence distribution and extreme values.

It is worth to mention that the wind gust information obtained from buoy E01 [B1] is measured in periods of five-second duration, and the provided values are the maximum value of all these five-second measurements in a ten- minute period at the anemometer height (4 meters).

4.4.6.1 Percentage frequency distribution

The following table summarizes the occurrence probability of the different ranges of wind gust obtained from the analysis of the raw data from buoy E01 [B1] . Wind gust is analyzed in 10-minute periods at a height of 4 meters.

However, it is worth to mention that in this raw data form buoy E01 [B1] the wind gust is considered as the maximum 5 seconds sustained speed in each 10 minute measurement period.

		Annual%
Wind Gust [m/s]	U <2	4,27
	2< U <3	8,09
	3< U <4	10,11
	4< U <5	10,38
	5< U <6	9,72
	6< U <7	8,92
	7< U <8	8,13
	8< U <9	7,40
	9< U <10	6,78
	10< U <11	5,92
	11< U <12	4,87
	12< U <13	4,08
	13< U <14	3,20
	14< U <15	2,47
	15< U <16	1,76
	16< U <17	1,23
	17< U <18	0,82
	18< U <19	0,62
	19< U <20	0,47
	20< U <21	0,33
	21< U <22	0,21
	22< U <23	0,11
	23< U <24	0,06
	24< U <25	0,03
	25< U <26	0,02
	U >26	0,02

Table 23: Wind gust percentage frequency distribution

¹¹ This wind model can be check in IEC-61400 [B8]

4.4.6.2 Wind Gust reference values (1, 5, 10 and 50 years return period)

The probability density function is fitted to a Weibull Distribution. The defining parameters associated to this distribution are the following:

Weibull Parameters for wind Gust distribution	
Scale coefficient	7,525
Shape coefficient	1,765
Location coefficient	0,010
R^2	0,962

Table 24: Weibull distribution parameters for the wind gust in GoM

Based into this Weibull distribution, the following parameters are obtained for different return periods.

Wind Gust (4 m)	Return Period [years]	Wind Gust [m/s]
	50	40,0
	10	38,1
	5	37,2
	1	35,2

Table 25: Wind gust reference values at measurement height

4.5 Wave Climate

Main source of information is raw data from NERACOOS, buoy E01 [B1] . Information available at Gulf of Maine provided by this monitoring system is listed below:

- Wave height: Wave heights are measured in continuous periods of 30 min duration, afterwards the mean of these values is provided as the significant wave height for that 30 min period.
- Wave period: Corresponds to the peak period of the time series recorded during the aforementioned 30 min interval.

Since the buoy E01 [B1] does not provide directional data neither does the buoy 44005, indicative values have been obtained from buoy 44007.

4.5.1 Significant Wave Height- Peak Period Distribution

4.5.1.1 Hs/Tp Scattergrams

This significant wave height/peak period scatter diagram is used to represent the probability of occurrence of each certain wave height and peak period combination for the Gulf of Maine selected site.

		Tp (s)								
		1<Tp<2	2<Tp<3	3<Tp<4	4<Tp<5	5<Tp<6	6<Tp<7	7<Tp<9	9<Tp<11	Tp>11
Significant Wave Height [m]	<1	0,03%	4,69%	7,29%	7,02%	3,91%	5,91%	13,49%	6,27%	0,08%
	1< Hs <2		0,00%	0,92%	6,64%	6,85%	7,32%	7,90%	8,36%	0,16%
	2< Hs <3			0,00%	0,09%	0,55%	2,71%	2,91%	3,31%	0,15%
	3< Hs <4				0,00%	0,01%	0,12%	1,11%	1,04%	0,08%
	4< Hs <5						0,00%	0,19%	0,47%	0,04%
	5< Hs <6							0,02%	0,21%	0,01%
	6< Hs <7								0,08%	0,01%
	7< Hs <8								0,02%	0,01%
	Hs >8								0,00%	0,00%

Table 26: GoM significant wave height-peak period distribution

In this table, cells with a value of “0,00%” means this wave condition has happened in very few cases unlike blank cells, which means those wave height-period combination have not happened in all the available historical data (2003-2015).

4.5.1.2 Wave height's associated Weibull Distribution

According to DNV OS-C205 [B7] , Sec 2.3.1.2, unless data indicate otherwise, a Weibull distribution can be assumed for the arbitrary Significant Wave Height (Hs). Therefore, a Weibull distribution is selected to represent the long-term probability distributions of the Hs.

$$F_{Hs}(h) = 1 - \exp\left(-\frac{h - \delta}{A}\right)^k$$

Weibull coefficients fitting the percentage frequency distribution presented in the previous section are:

Weibull Parameters	
Scale coefficient (A)	0,744
Shape coefficient (k)	0,976
Location coefficient (δ)	0,015
R ²	0,990

Table 27: Weibull defining parameters of wind gust distribution

The good level of correlation of this distribution with respect to the distribution directly obtained from the raw data is illustrated in Figure 21.

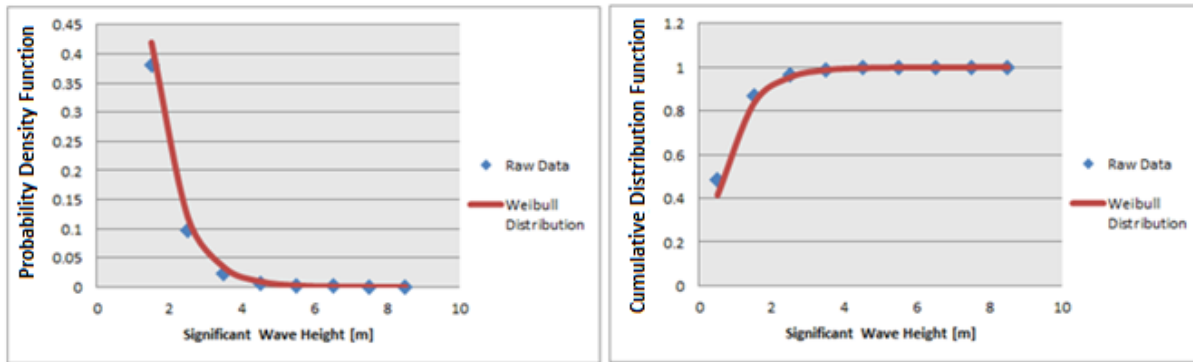


Figure 21: Significant wave height from raw data and Weibull distribution comparison

4.5.1.3 Wave characteristic reference values (1, 5, 10 and 50 years return period)

From this Weibull distribution, the wind climate reference values are gathered in the following table:

Wave Climate	Return period [years]	Significant Wave Height [m]	Tp [s]
	50	10,9	9-16 ¹²
	10	9,4	13,8
	5	8,9	13,4
	1	7,7	12,4

Table 28: Reference values for GoM significant wave height and its associated peak periods

For each of these values, the wave peak period has been extrapolated as the most probable value associated to that height, in order to do so a curve fitting analysis (see below) has been performed to allow for determining the most probable values to be associated to those wave heights that are not contained within the available data.

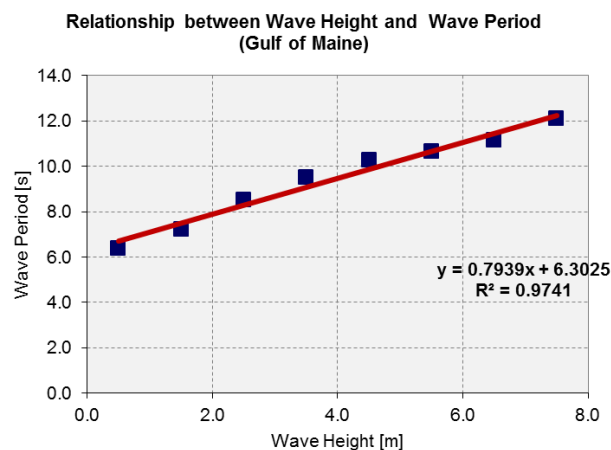


Figure 22: Extrapolation curve for Peak period-Significant wave height correlation

4.5.2 Wave Direction

It is worth to remember that the wind direction characterization is not developed with the same reference buoy E01 [B1] than all the other environmental conditions, since wave direction measurements are not available. Instead, wave direction are defined using data from buoy 44007 (position of this buoy can be seen in Figure 15), also near the selected site.

¹² This range of period has been selected taking into account the highest wave measured in site, which can be checked in the scatter diagram of previous sections. If a certain value of the peak period is needed, it can be calculated with the extrapolation procedure detailed below the Table 28, which gives the most probable peak period associated to the 50 year return period wave of 14,8 s.

4.5.2.1 Wave Rose

		Distribution [%]
Wave direction [°] ¹³	0	1,01
	30	1,10
	60	1,83
	90	16,01
	120	38,00
	150	29,51
	180	8,30
	210	1,73
	240	0,94
	270	0,44
	300	0,51
	330	0,83

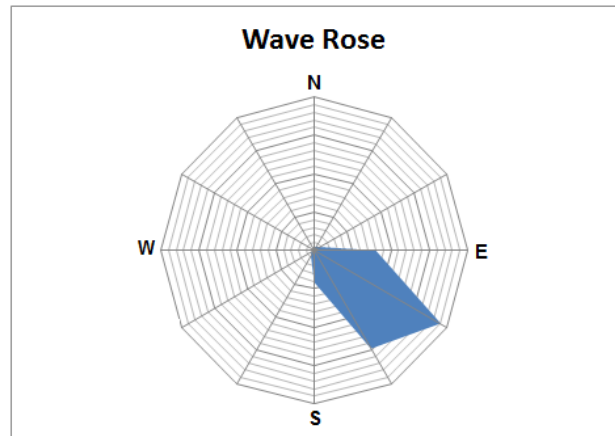


Table 29: GoM wave rose

¹³ Considered bin size: 30°

4.5.2.2 Wave direction Scatter Diagrams

		Wave Direction[°]											
		350-20	20-50	50-80	80-110	110-140	140-170	170-200	200-230	230-260	260-290	290-320	320-350
Significant Wave Height [m]	<0,4	0,50%	0,30%	0,60%	2,60%	6,90%	4,40%	0,90%	0,40%	0,30%	0,10%	0,20%	0,30%
	0,5-1,4	0,60%	0,70%	1,10%	10,30%	27,00%	21,60%	6,70%	1,20%	0,70%	0,20%	0,30%	0,50%
	1,5-2,4			0,20%	2,50%	3,30%	3,00%	0,80%	0,01%	0,01%	0,10%	0,01%	
	2,5-3,4			0,01%	0,50%	0,50%	0,50%	0,01%					
	3,5-4,4			0,01%	0,10%	0,10%	0,10%						
	4,5-5,4			0,01%	0,01%	0,10%	0,01%						
	5,5-6,4				0,01%	0,10%							
	6,5-7,4												
	7,5-8,4			0,01%		0,01%							
	>8,5												
(*) 0° direction is corresponding to North direction.													

Table 30: Wave direction for GoM selected site

4.5.3 Wave height occurrence distribution

The following table summarizes the occurrence probability associated to the significant wave height in the Gulf of Maine selected site. This occurrence probability is shown for each month and can be used to determine the percentage of time at which a particular wave height does not exceed a certain value.

		Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Significant Wave Height [m]	Hs <= 0	0,01%	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Hs <= 0,5	8,30%	9,08%	13,35%	10,77%	15,88%	21,47%	17,05%	31,19%	20,11%	19,45%	10,79%	9,31%
	Hs <= 1	40,90%	41,74%	44,11%	47,01%	58,03%	73,45%	76,69%	82,35%	67,44%	56,07%	39,44%	39,64%
	Hs <= 1,5	66,48%	66,24%	66,87%	72,15%	84,74%	91,28%	96,21%	95,29%	88,12%	75,35%	65,07%	64,03%
	Hs <= 2	81,61%	81,92%	82,00%	85,74%	94,84%	97,04%	99,71%	98,06%	96,13%	86,64%	81,25%	80,14%
	Hs <= 2,5	90,34%	90,68%	90,70%	92,95%	98,31%	99,04%	99,96%	99,07%	98,82%	93,23%	90,11%	88,51%
	Hs <= 3	94,87%	95,09%	95,39%	96,97%	99,50%	99,58%	100,00%	99,43%	99,54%	96,38%	95,23%	92,88%
	Hs <= 3,5	97,32%	97,21%	97,52%	98,55%	99,76%	99,83%	100,00%	99,61%	99,86%	98,00%	97,68%	95,58%
	Hs <= 4	98,67%	98,46%	98,55%	99,17%	99,88%	99,96%	100,00%	99,82%	99,95%	98,72%	98,73%	97,44%
	Hs <= 4,5	99,38%	99,15%	99,23%	99,50%	99,96%	99,98%	100,00%	99,89%	99,98%	99,31%	99,32%	98,43%
	Hs <= 5	99,67%	99,44%	99,61%	99,65%	99,98%	99,99%	100,00%	99,92%	100,00%	99,64%	99,59%	98,97%
	Hs <= 5,5	99,82%	99,62%	99,78%	99,77%	99,99%	100,00%	100,00%	99,99%	100,00%	99,86%	99,79%	99,47%
	Hs <= 6	99,92%	99,76%	99,91%	99,87%	99,99%	100,00%	100,00%	100,00%	100,00%	99,91%	99,90%	99,75%
	Hs <= 6,5	99,97%	99,85%	99,95%	99,92%	99,99%	100,00%	100,00%	100,00%	100,00%	99,95%	99,95%	99,87%
	Hs <= 7	99,99%	99,94%	99,97%	99,96%	100,00%	100,00%	100,00%	100,00%	100,00%	99,99%	99,98%	99,92%
	Hs <= 7,5	100,00%	99,96%	99,99%	99,98%	100,00%	100,00%	100,00%	100,00%	100,00%	99,99%	100,00%	99,96%
	Hs <= 8	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Table 31: Significant wave height occurrence probability distribution

This occurrence distribution can be also represented within the following graphic, which provides the non-exceedance probability of certain significant wave heights for the different months of the year, and gives an illustrative view of how likely is that a given significant wave height will not be overcome during the month under consideration.

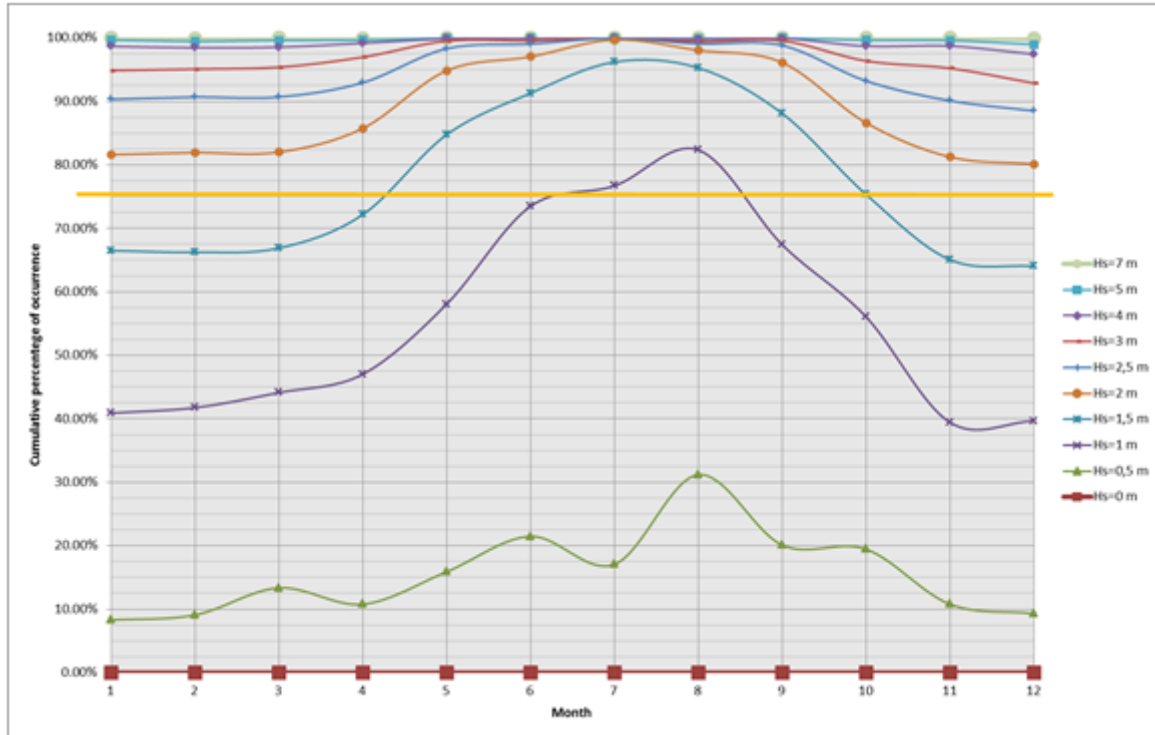


Figure 23: Significant wave height occurrence probability graphic representation

4.5.4 Wave spectrum model

Last point pending for the complete definition of the selected site in Gulf of Main is the selection of the most accurate wave spectrum model or, in other words, to characterize the spectral density of the wave climate in this site.

At this point, two different wave spectra are considered as possible depending on the certain site characteristics:

- Pierson-Moskowitz spectrum, which is normally advisable for fully developed seas.
- Jonswap spectrum, that is better suited to “wind seas”.

On the base of the data achieved regarding to the wind-wave correlation (see section 4.6) and also to the wind and wave roses, it is noticed that the wave climate is not very bound to the wind conditions. This indicates that, in the Gulf on Maine’s site, the most probable wave climate is due to a “swell sea” that points as the most advisable wave spectrum model the Pierson-Moskowitz model.

4.6 Wind-Wave Combined Conditions

4.6.1 Wind-Wave climate Scattergrams

These scatter diagrams were generated from raw data of buoy buoy E01 [B1] . Therefore, due to the non-availability of wave direction information within this source, only the correlation between wind and wave overall characteristics are going to be provided, not being possible to differentiate between incoming wave directions.

		Significant Wave Height [m]								
		Hs <1	1 < Hs <2	2 < Hs <3	3 < Hs <4	4 < Hs <5	5 < Hs <6	6 < Hs <7	7 < Hs <8	Hs >8
Wind Speed at 10m [m/s]	$u_{10}<1$	681	410	59	14	8				
	$1 < u_{10}<2$	3174	2291	401	84	24	6	5	1	
	$2 < u_{10}<3$	5501	4003	726	162	73	7	4		
	$3 < u_{10}<4$	6043	4515	851	197	79	26	3		1
	$4 < u_{10}<5$	5887	4867	894	260	101	36	8	1	
	$5 < u_{10}<6$	5376	5073	1057	256	110	48	19	9	
	$6 < u_{10}<7$	4094	4633	1147	339	130	43	10	5	4
	$7 < u_{10}<8$	2945	5064	1276	500	147	38	17	4	3
	$8 < u_{10}<9$	1694	4745	1623	496	163	63	9	3	2
	$9 < u_{10}<10$	1121	4120	1843	506	162	47	31		1
	$10 < u_{10}<11$	687	3216	1956	570	151	47	33	5	2
	$11 < u_{10}<12$	441	2018	1933	564	142	51	24	6	
	$12 < u_{10}<13$	321	1181	1762	680	185	69	18	6	
	$13 < u_{10}<14$	189	617	1311	706	196	53	11	2	2
	$14 < u_{10}<15$	142	310	676	625	187	53	23	5	1
	$15 < u_{10}<16$	90	187	381	507	209	76	28	8	3
	$16 < u_{10}<17$	67	92	132	332	207	70	19	8	5
	$17 < u_{10}<18$	51	68	55	157	188	72	20	5	
	$18 < u_{10}<19$	43	34	26	52	97	53	28	8	8
	$19 < u_{10}<20$	12	22	7	15	31	44	19	9	4
	$20 < u_{10in} < 21$	4	3	2	3	18	23	15	13	8
	$21 < u_{10}<22$	4	3			6	11	7	4	1
	$u_{10}>22$	4	5	1		2	6	9	4	12

Table 32: 10 minute wind speed at 10 m – significant wave height occurrence distribution

Based on this information, studies have been performed to preview the most probable wind speed associated to each significant wave height. This formula is intended to ease the calculation of the met-ocean conditions required within the WP7 to establish the DLCs.

To ensure the best correlation possible with the real sea state conditions (represented by the achieved raw data), three different equations have been checked:

- Second order polynomial equation:

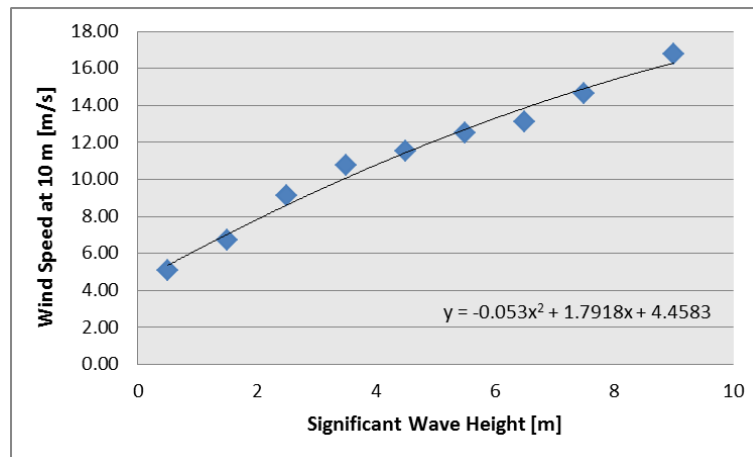


Figure 24: Second order polynomial equation

- Third order polynomial equation:

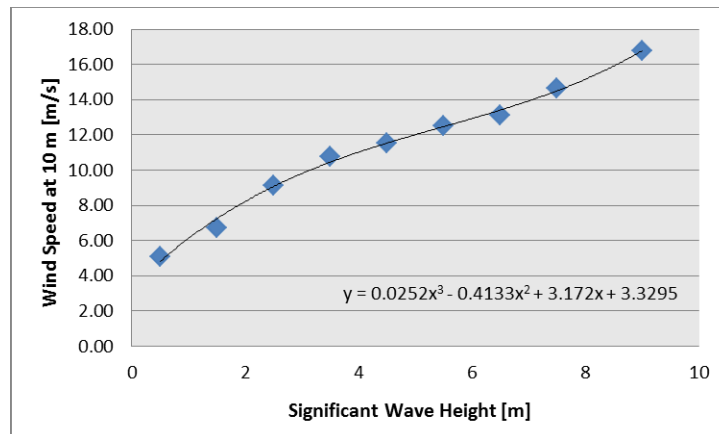


Figure 25: Third order polynomial equation

- Fifth order polynomial equation:

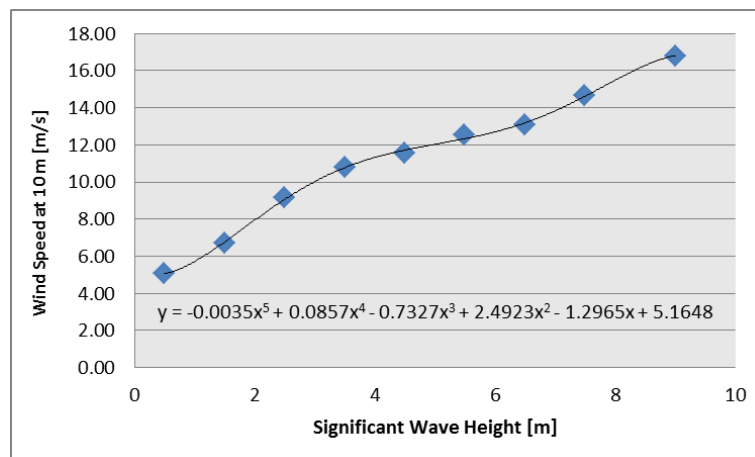


Figure 26: Fifth order polynomial equation

Following table summarizes the different values checked during the selection of the most accurate relation between the significant wave height and its associated wind speed from the aforementioned possibilities:

		Wind speed [m/s]		
		2 nd Order	3 rd Order	5 th Order
Significant wave height [m]	1	6,20	6,11	5,71
	3	9,36	9,81	10,01
	5	12,09	12,01	12,03
	7	14,40	13,93	13,84
	9	16,29	16,77	16,84
	11	17,75	21,75	8,30

Table 33: Comparison of three proposed equations for the wind-wave correlation

On the base of this information, it is selected the **3rd order polynomial equation** as the most appropriate for the wind/wave correlation in Gulf of Maine because:

- The 2nd order equation is less accurate than the other two possible solutions.
- The deviation of the 5th order equation when calculation wind speeds associated to significant wave heights out of the scatter diagram ranges is large.

The table below shows the relation of the wind direction and the significant wave height:

		Significant Wave Height [m]								
		<1	1 < Hs < 2	2 < Hs < 3	3 < Hs < 4	4 < Hs < 5	5 < Hs < 6	6 < Hs < 7	7 < Hs < 8	Hs > 8
Wind Direction [°] ¹⁴	0	1802	2841	1260	486	201	52	38	9	16
	22,5	1527	2653	1141	478	214	77	27	10	7
	45	1587	2649	1005	388	139	55	25	6	6
	67,5	1698	2266	796	239	90	55	20	4	7
	90	1569	1553	484	212	67	13	1		
	112,5	1531	1451	417	201	96	28	16	5	1
	135	1764	1568	452	179	97	30	4	1	
	157,5	2356	2155	566	282	82	34	11	2	1
	180	3643	3695	1026	285	79	20	9	2	
	202,5	4571	5063	1378	480	128	30	8	8	2
	225	4075	4557	1433	487	124	41	9	3	1
	247,5	3074	3511	1238	501	216	110	48	7	
	270	2460	2964	1418	645	226	112	40	16	1
	292,5	2494	3227	1822	842	344	140	37	16	5
	315	2347	3947	2135	793	294	90	50	11	2
	337,5	2073	3377	1548	527	219	55	17	6	8

Table 34: Wind direction at 10 m – significant wave height occurrence distribution

4.6.2 Wind-Wave misalignments

No met-ocean data is available about the correlation of wind direction and wave direction.

¹⁴ Considered bin size: 22,5°

4.7 Currents Data

Information of the currents characteristics can also be acquired from [B1]. Within this reference, raw data of buoy E01 [B1] is taken for the surface current direction and speed characterization.

This current data is acquired for a considerably long measurement period (since 2003 to 2015), with enough accuracy and periodicity. However, when reviewing this data, it has been noticed three singular periods, where the registered current speed can be considered as outliers.

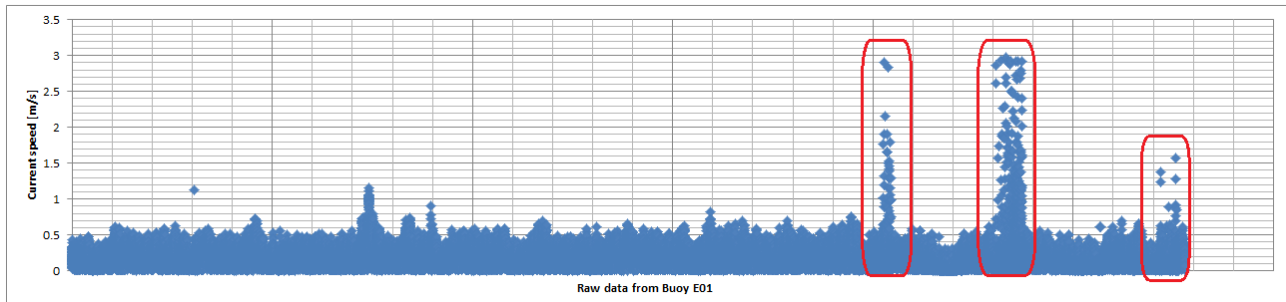


Figure 27: Raw data for current speed of buoy E01 [B1]

In order to avoid these extremely high values (assumed to be coming from inaccuracies in the measurement of the buoy), the raw data has been processed prior to the characterization of the current climate in the site using a “moving average” method.

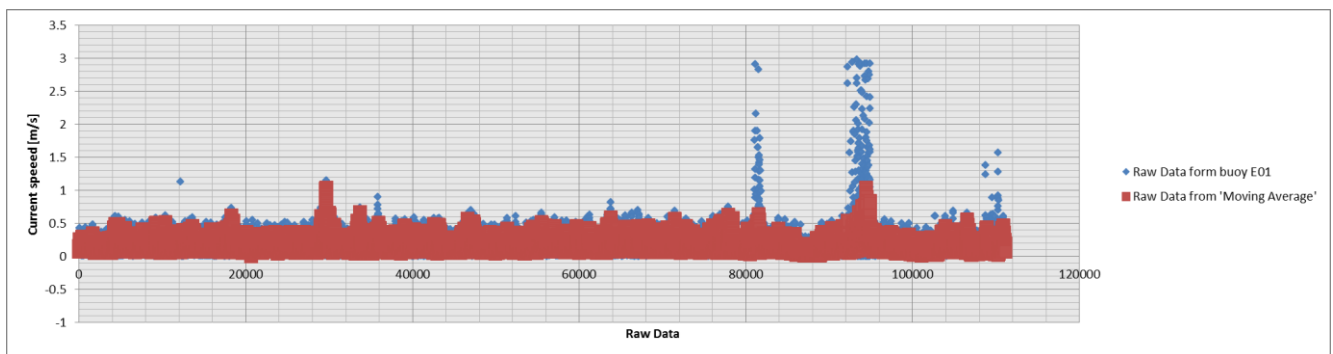


Figure 28: Comparison between the buoy data and the data obtained using a “moving average”

4.7.1 Current Induced by Wind

For the estimation of the “wind component” of the current speed, DNV OS-C205 [B7] recommends an expression that allows calculating it from the mean wind speed at 10 m height:

$$v_{c,wind}(0) = k U_{1 \text{ hour}, 10 \text{ m}} \text{ where } k = 0.015 \text{ to } 0.03$$

A supposition must be done for estimating the k coefficient. It is noticed that, according to the scatter diagrams of the section 4.7.6 for wind and currents directionalities, there is a big influence of the wind climate in the current direction. Due to this, a $k=0,021$ is taken as reference value, and, therefore, the mean speed of the current induced by wind in the sea surface is considered 0,154 m/s.

4.7.2 Deep Water Current

The current induced by tides, also called deep-water current component, has been estimated at the sea surface as the difference between the total mean current speed and the “wind component” of that current.

$$v_{c, \text{ tide}} = 0,016 \text{ m/s}$$

4.7.3 Current Speed Profile

DNV OS-C205 [B7] (section 4.1.4) recommended practices are used for the calculation of the current speed at different depths, due to the unavailability of actual measurements. In this section, a different profile for each of the two components of the current speed is defined:

- Current induced by wind: Wind current profile is represented by a lineal profile.

$$v_{c, \text{ wind}}(z) = v_{c, \text{ wind}}(0) \cdot \left(\frac{d_0 + z}{d_0} \right) \text{ for } -d_0 \leq z \leq 0$$

Where d_0 is taken as half of the water depth at Maine following DNV recommendations, hence $d_0 = 65 \text{ m}$.

- Current induced by tides profile: Tide current profile is represented by a Potential Profile ($\alpha=0,14$):

$$v_{c, \text{ tide}}(z) = v_{c, \text{ tide}}(0) \cdot \left(\frac{d + z}{d} \right)^\alpha \text{ for } z \leq 0$$

Once these current speeds' profiles have been defined, and taking as reference depth the total depth defined for the Gulf of Maine site (130 m), the current speed at different depths for each of the components of the current speed mentioned above (wind current and tidal current), as well as the total current speed is the following.

Current Profile			
Depth	Wind component	Tidal component	Total Current speed
[m]	[m/s]	[m/s]	[m]
Surface	0.154	0.016	0.170
-1	0.152	0.016	0.168
-2	0.149	0.016	0.165
-5	0.142	0.016	0.158
-10	0.130	0.016	0.146
-20	0.107	0.016	0.122
-30	0.083	0.015	0.098
-40	0.059	0.015	0.074
-50	0.036	0.015	0.051
-60	0.012	0.015	0.027
-70	0.000	0.014	0.014
-80	0.000	0.014	0.014
-90	0.000	0.014	0.014
-100	0.000	0.013	0.013
-110	0.000	0.012	0.012
-120	0.000	0.011	0.011
-130	0.000	0.000	0.000

Figure 29: Current speed profile

4.7.4 Current Direction

This data is obtained after processing the raw data of the buoy E01 [B1] , which measures the surface current speed and direction.

Current Direction Distribution [°] 15	0	3%
	22,5	3%
	45	3%
	67,5	4%
	90	4%
	112,5	5%
	135	5%
	157,5	6%
	180	7%
	202,5	9%
	225	12%
	247,5	14%
	270	11%
	292,5	7%
	315	5%
	337,5	4%

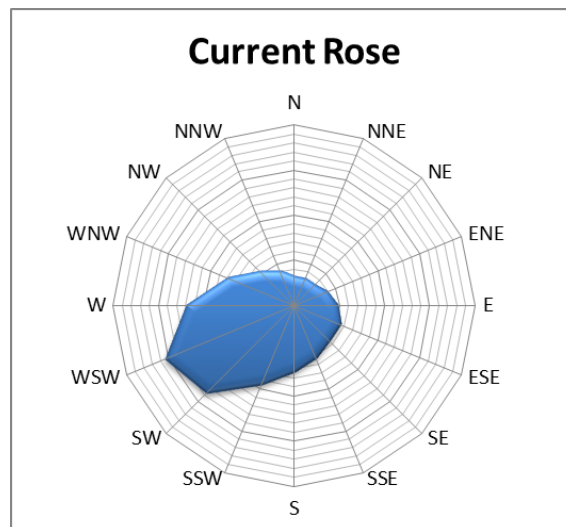


Table 35: Current rose for GoM

This current direction can also be represented in front of its associated current speed as in the following scatter diagram.

¹⁵ Considered bin size: 22,5°

		Current Direction [°] ¹⁶															
		0	22,5	45	67,5	90	112,5	135	157,5	180	202,5	225	247,5	270	292,5	315	337,5
Current Speed [m/s]	$u_c < 0,10$	0,96%	1,03%	0,96%	1,04%	1,06%	1,11%	1,26%	1,45%	1,54%	1,65%	1,80%	1,74%	1,52%	1,30%	1,08%	1,07%
	$0,10 < u_c < 0,20$	1,53%	1,48%	1,47%	1,83%	2,25%	2,67%	2,70%	3,14%	3,68%	4,40%	5,34%	5,55%	4,64%	3,63%	2,70%	1,98%
	$0,20 < u_c < 0,30$	0,32%	0,27%	0,30%	0,50%	0,78%	0,98%	0,86%	0,93%	1,14%	2,01%	3,71%	4,39%	3,42%	1,97%	0,90%	0,49%
	$0,30 < u_c < 0,40$	0,04%	0,04%	0,05%	0,09%	0,15%	0,14%	0,15%	0,13%	0,23%	0,39%	1,12%	1,64%	0,89%	0,31%	0,08%	0,05%
	$0,40 < u_c < 0,50$	0,02%	0,01%	0,01%	0,02%	0,02%	0,04%	0,03%	0,03%	0,03%	0,09%	0,33%	0,43%	0,23%	0,03%	0,02%	0,02%
	$0,50 < u_c < 0,60$	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,02%	0,10%	0,18%	0,04%	0,01%	0,01%	0,01%
	$0,60 < u_c < 0,70$	0,00%	0,00%	0,00%	0,00%	0,01%	0,00%	0,00%	0,00%	0,00%	0,01%	0,02%	0,05%	0,01%	0,00%	0,00%	0,00%
	$0,70 < u_c < 0,80$	0,00%	0,00%	0,00%	0,00%	0,00%			0,00%	0,00%		0,00%	0,01%	0,00%	0,00%		0,00%
	$0,80 < u_c < 0,90$	0,00%						0,00%	0,00%		0,00%	0,00%	0,00%			0,00%	0,01%
	$0,90 < u_c < 1,00$	0,00%	0,00%									0,01%	0,00%				0,00%
	$u_c > 1,00$	0,00%										0,01%	0,00%				
(*)A cell with a value of "0,00 %" means this condition has happened during the measurement period once or in too few cases																	

Table 36: Current direction in GoM

¹⁶ Considered bin size: 22,5°

4.7.5 Current characteristic reference values (1, 5, 10 and 50 years return period)

The current speed occurrence distribution has been fitted to a “three parameters” Weibull distribution.

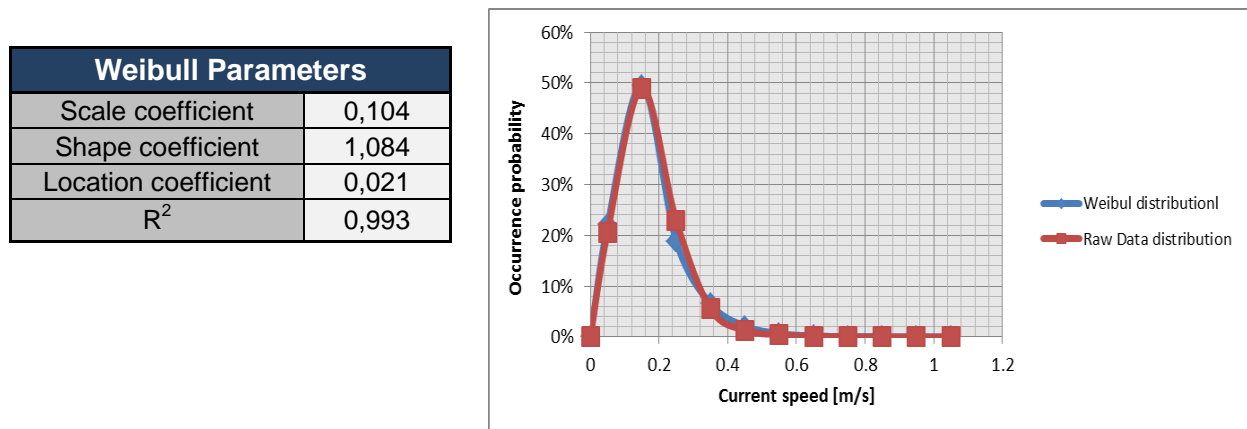


Table 37: Weibull parameters associated to the current speed distribution

Using this distribution, the extreme current speed values are:

Current Speed ¹⁷	Return Period [years]	Total Current speed [m/s]	Wind induced current speed [m/s]	Tides induced current speed [m/s]
	50	1.13	0.70	0.43
	10	1.0	0.66	0.34
	5	0.9	0.64	0.31
	1	0.82	0.59	0.23

Table 38: Surface current speed reference values

It is assumed that the same procedure as in section 4.7.3 can be followed for the calculation of the current speed profile at different depths, being calculated the total current speed as the sum of its two components (current induced by wind¹⁷ and current induced by tides), considering a lineal profile for the wind component and a 0,14 potential profile for the current induced by tides.

¹⁷ The speed of the current induced by wind and the speed of the current induced by tides have been obtained under the assumption that the same procedure as for the mean current speed calculation is applicable. This procedure is explained in detail in sections 4.7.1 and 4.7.2.

4.7.6 Wind-Current Combined Conditions

		Current Speed at surface [cm/s]				
		$u_c < 25$	$25 < u_c < 50$	$50 < u_c < 75$	$75 < u_c < 100$	$100 < u_c < 125$
Wind Speed at 10m [m/s]	$u_{10} < 1$	0,47%	0,37%	0,04%	0,00%	
	$1 < u_{10} < 2$	2,93%	1,89%	0,28%	0,02%	
	$2 < u_{10} < 3$	4,99%	3,17%	0,41%	0,02%	0,00%
	$3 < u_{10} < 4$	5,79%	3,80%	0,53%	0,03%	0,00%
	$4 < u_{10} < 5$	5,93%	3,92%	0,53%	0,02%	
	$5 < u_{10} < 6$	5,65%	3,73%	0,46%	0,02%	0,00%
	$6 < u_{10} < 7$	5,52%	3,39%	0,32%	0,02%	
	$7 < u_{10} < 8$	5,00%	3,07%	0,41%	0,01%	
	$8 < u_{10} < 9$	4,37%	2,74%	0,34%	0,02%	
	$9 < u_{10} < 10$	4,02%	2,64%	0,33%	0,01%	
	$10 < u_{10} < 11$	3,07%	2,31%	0,28%	0,01%	
	$11 < u_{10} < 12$	2,57%	1,91%	0,23%	0,01%	
	$12 < u_{10} < 13$	2,06%	1,53%	0,25%	0,00%	
	$13 < u_{10} < 14$	1,40%	1,24%	0,22%	0,00%	
	$14 < u_{10} < 15$	0,93%	0,97%	0,16%	0,01%	
	$15 < u_{10} < 16$	0,58%	0,69%	0,12%	0,00%	
	$16 < u_{10} < 17$	0,35%	0,38%	0,12%	0,01%	0,00%
	$17 < u_{10} < 18$	0,20%	0,29%	0,09%	0,01%	0,00%
	$18 < u_{10} < 19$	0,10%	0,19%	0,06%	0,00%	0,00%
	$19 < u_{10} < 20$	0,06%	0,08%	0,04%	0,01%	
	$20 < u_{10} < 21$	0,03%	0,05%	0,04%	0,00%	
	$21 < u_{10} < 22$	0,01%	0,03%	0,01%	0,00%	
	$u_{10} > 22$	0,00%	0,02%	0,01%		

Table 39: Wind-Current combined conditions: Speed Correlation

		Wind Direction [°] ¹⁸															
		0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
Current Direction [°] ¹⁸	0	283	257	334	312	260	280	314	417	544	598	516	400	304	283	351	291
	22.5	251	209	211	243	177	237	296	383	674	818	683	446	364	397	394	276
	45	201	164	178	154	140	160	223	366	604	897	656	516	433	400	356	260
	67.5	159	125	106	126	125	124	167	277	463	769	684	494	370	365	313	200
	90	136	113	95	96	110	81	143	281	467	704	643	489	363	364	294	207
	112.5	146	118	110	127	112	113	156	268	541	791	742	585	459	453	389	249
	135	265	169	193	178	179	155	202	309	604	955	893	804	753	729	573	367
	157.5	481	324	297	242	218	208	220	335	579	907	960	861	943	1069	1166	659
	180	756	530	429	355	248	219	198	279	385	536	660	602	637	904	1289	927
	202.5	724	522	521	308	214	158	156	195	227	277	311	292	317	456	735	731
	225	459	421	365	241	175	136	118	127	144	191	187	170	145	223	313	384
	247.5	303	287	255	185	119	124	87	71	87	103	110	93	87	140	199	231
	270	231	260	205	164	110	126	66	71	100	105	85	87	84	95	151	170
	292.5	224	262	294	197	150	109	86	77	117	142	86	103	94	104	156	186
	315	232	304	272	252	201	160	137	124	160	196	152	144	115	125	194	213
	337.5	250	295	329	343	266	249	259	230	285	329	292	232	175	199	237	236

Table 40: Wind-Current combined conditions: Direction Correlation

¹⁸ Considered bin size: 22,5°

4.8 Soil Conditions

Due to the lack of detailed information regarding to the soil characterization on site, soil conditions are established on the base of predefined standard profiles. The available in-site information is taken as reference. This general information of the soil characteristics can be achieved from the reference maps of NOAA [B4] .

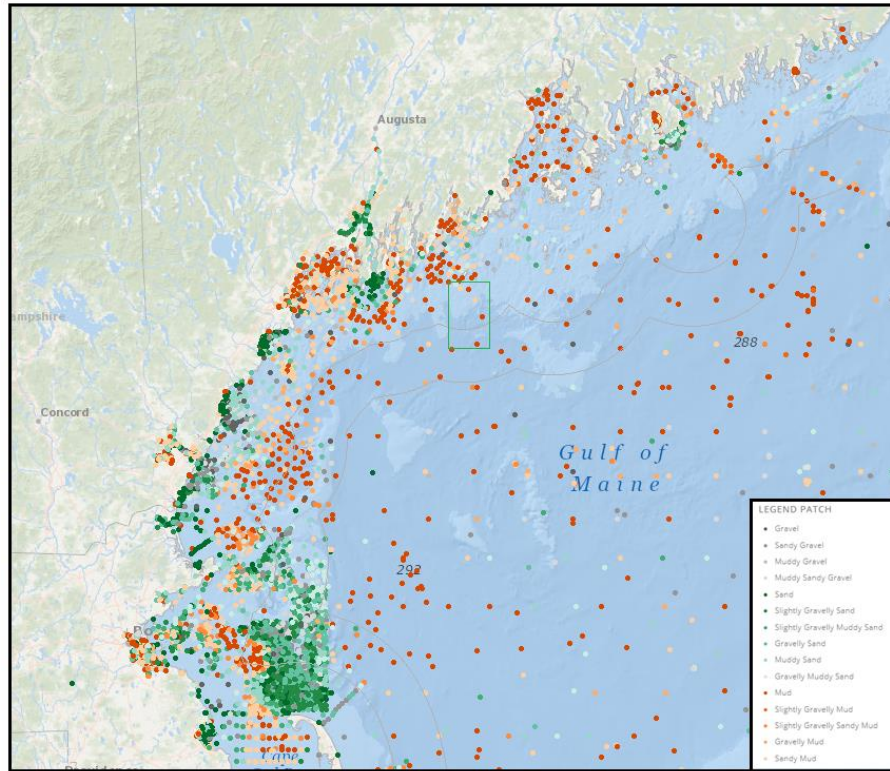


Figure 30: Soil characterization from NOAA reference

In this figure, the green rectangle remarks the zone near the selected site for the Gulf of Maine. Inside this zone, two different types of soil can be defined: mud (red points) and sandy mud (light orange points). On the base of that, it has been defined a modelled soil profile of medium compressive resistance.

Soil Profile Characteristics			
Layer	Soil Type	Layer Length [m]	Cu [kPa]
1	Very Dense Sand	4	35
2	Soft Clay	6	60
3	Stiff Clay	9	200

Table 41: Medium compressive strength soil profile designed for GoM

4.9 Other Environmental Conditions

4.9.1 Ice (sea spray/precipitation)

Information available for the ice characterization of Gulf of Maine is not site specific.

[B3] provides some guidance values based on NOAA researchers experience for a preliminary estimation of ice accumulation in offshore floating structures.

PR (m·°C/s)	< 20.6	20.6 < PR < 45.2	PR > 45.2	PR > 70.0
Description	light	moderate	heavy	extreme
Ice Accumulation (cm/hr)	< 0.7	0.7-2.0	>2.0	NA

Figure 31: Thickness increasing due to icing

This reference table is based on the PR ration, which results as a consequence of the site environmental conditions following this empirical formula:

$$PR = \frac{V_a (T_f - T_a)}{1 + 0.4 (T_s - T_f)}$$

Where V_a is the wind speed in m/s, T_a is the air temperature, T_s is the sea surface temperature [°C] and T_f is the freezing point of sea water [°C].

4.9.2 Sea Water Characteristics

The information regarding to the sea water characteristics is also taken from the reference buoy E01 [B1] Although the most adequate profile for the water characteristics at different depths is not given in the reference, the sea water information is given at three different depths, 1, 20 and 50 meters.

4.9.2.1 Temperature

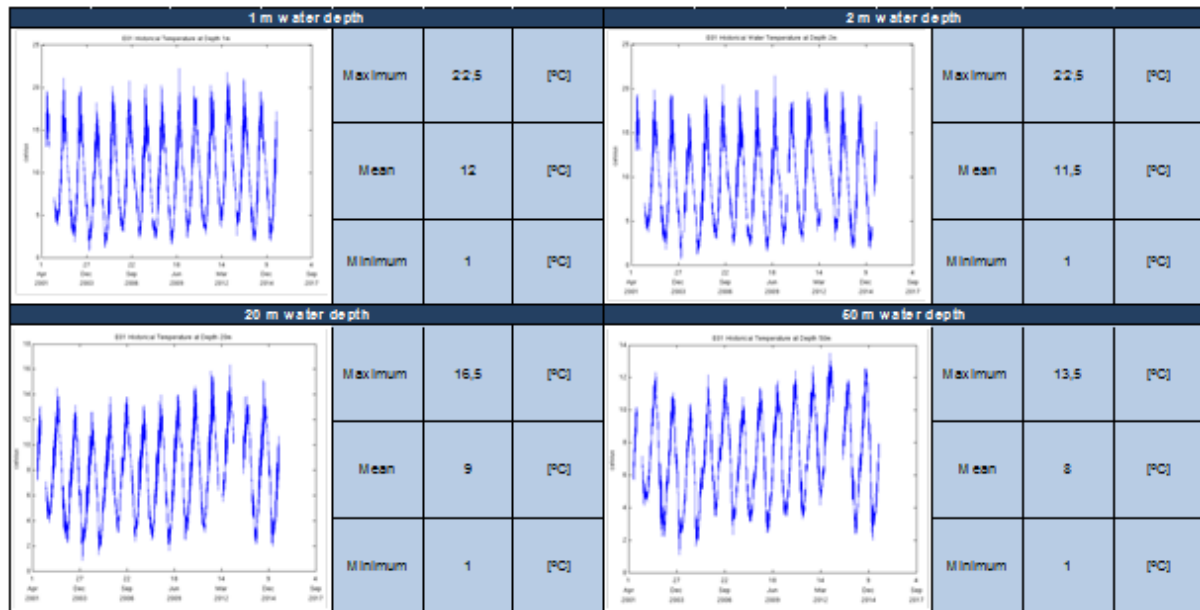


Figure 32: Water temperature at 1, 2, 20 and 50 meters depth

To ensure the validity of the NOAA measurements, this collected data has been compared to annual reports of the Northeast Fisheries Science Center [B9] :

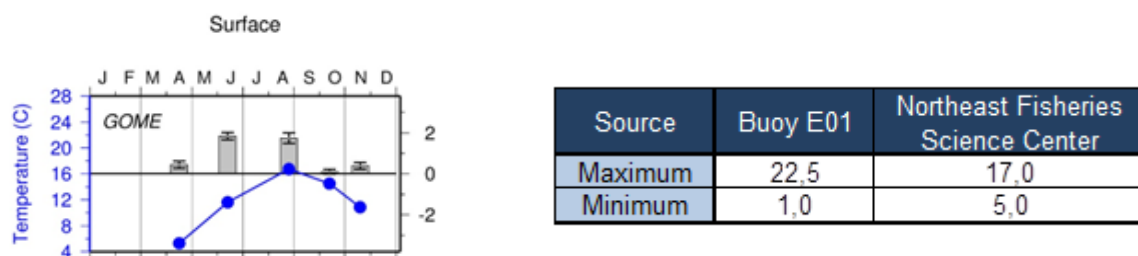


Figure 33: Water temperature [°] at the sea surface comparison

It shall be noted that the surface water temperature maximum and minimum values for the year 2010, are inside the range of maximum and minimum temperatures registered by buoy E01 [B1] since 2001.

4.9.2.2 Density

Regarding the water density, the figures provided by NOAA buoy, in order to ensure an accurate representation of its variation, represent the density value above the fresh water density. According to this point, the real water density is 1.000 kg/m^3 plus the value on the figures.

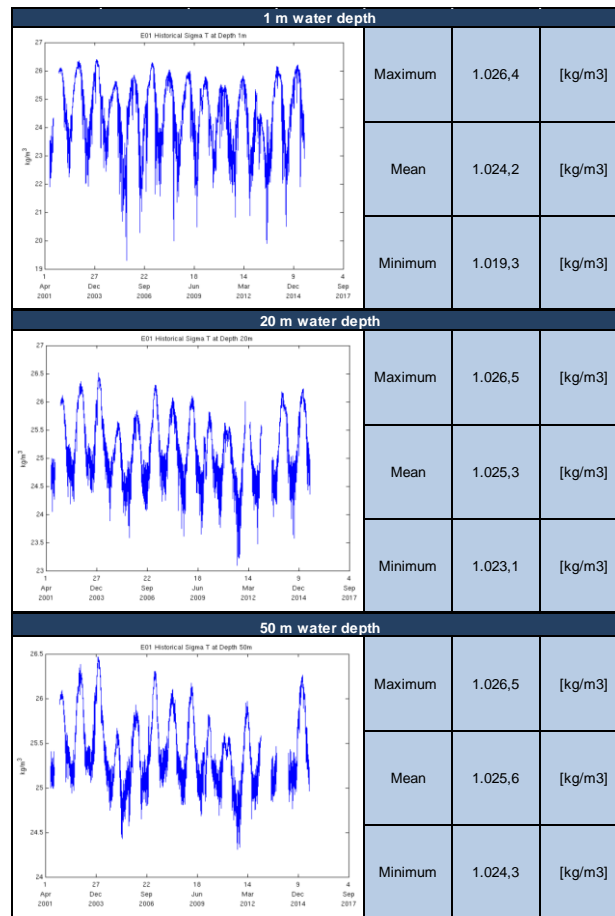


Figure 34: Water density for 1, 20 and 50 meters depth

4.9.2.3 Salinity

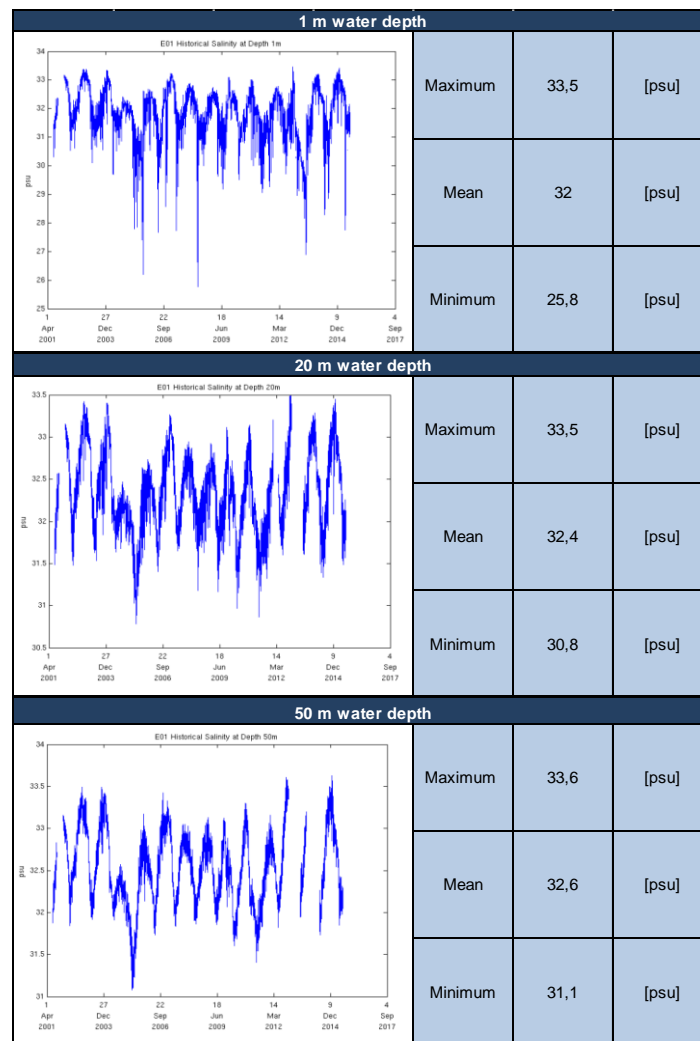


Figure 35: Water salinity for 1, 20 and 50 meters depth

The same validation procedure as in case of the sea water temperature (section 4.9.2.1), has been done with the salinity value of NOAA buoy using annual reports of Northeast Fisheries Science Center [B9] for the sea climate conditions.

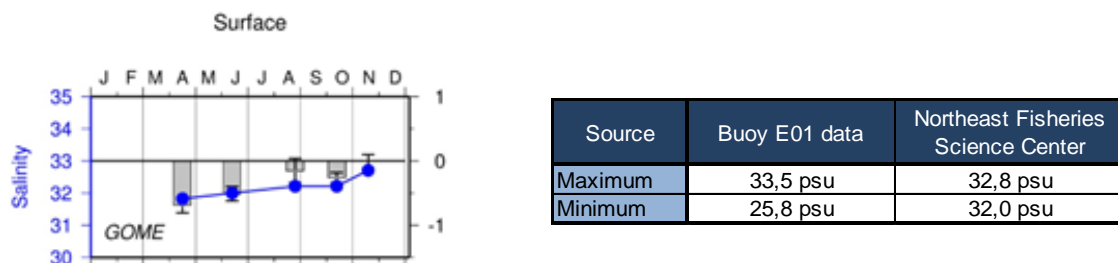


Figure 36: Water salinity comparison between the two sources of information

4.9.3 Air Characteristics

4.9.3.1 Temperature

The same reference as in case of the sea water characterization (buoy E01 [B1]) was used. However, for air characteristics only the value at 3m above water line is given.

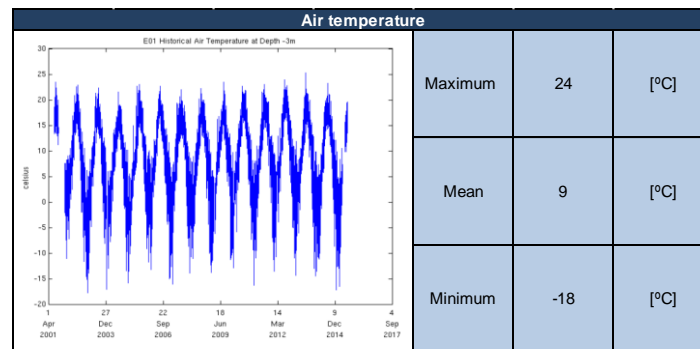


Figure 37: Air temperature measured by buoy E01 [B1] since 2001

4.9.3.2 Density

No specific information is available regarding to the air density.

Following the IEC 61400-1 [B8] standard it is selected a value of 1.225 kg/m³ for the air density.

4.9.4 Marine Growth

The marine growth is the accumulation of marine organism on a surface in the water. A reference value for the marine growth in a floating structure in the Gulf of Maine has been found in the US Deep-water report, which bases this study in the maintenance periods of E01 buoy.

In this report it has been noticed that the thickness increasing due to biofouling, in general, starts in the month of March/April and slows down in September/October. At each of the maintenance periods, the average thickness increasing due to marine growth is measured to be about 150 mm.



Figure 38: On the right marine growth in summer and on the left marine growth in winter in buoy E01.

A qualitative assessment of the most common species and the biological density associated to each one of them can be found at [B3] the most important sources of marine growth for the selected site some species of mussels (blue and tiger mussels), worms and limpets.

Even though there is no site specific information of the growth of each of the species in the certain site, generic data, based on studies performed by the oil and gas industry, can be used for a preliminary estimation of the marine growth on the platform.

Type	Settlement season	Typical growth rates	Typical coverage (%)	Typical terminal thickness	Depth range (relative to MSL)	Comments
<i>Hard fouling</i>						
Mussels	July to October	25 mm in 1 year 50 mm in 3 years 75 mm in 7 years	100%	150 to 200 mm	0 to 30 m	But faster growth rates are found on installations in the southern North Sea
Solitary tubeworms	May to August	30 mm (in length) in 3 months	50-70%	About 10 mm (tubeworms lay flat on the steel surface)	0 to mudline	Coverage is often 100%, especially on new structures 1 to 2 years after installation. Tubeworms also remain as a hard, background layer when dead
<i>Soft fouling</i>						
Hydroids	April to October	50 mm in 3 months	100%	Summer: 30 to 70 mm Winter: 20 to 30 mm	0 to mudline	A permanent hydroid 'turf' may cover an installation and obscure the surface for many years
Plumose anemone	June to July	50 mm in 1 year	100%	300 mm	-30 m to -120 m (0 to -45 m on platforms in southern North Sea)	Usually settle 4 to 5 years after installation and can then cover surface very rapidly. Live for up to 50 years
Soft coral	January to March	50 mm in 1 year	100%	About 200 mm	-30 m to -120 m (0 to -45 m on platforms in southern North Sea)	Often found in association with anemones
<i>Seaweed fouling</i>						
Kelp	February to April	2 m in 3 years	60-80%	Variable, but up to 3 m	-3 m to -15 m	May be several years before colonisation begins but tenacious holdfast when established. Present on some installations in northern and central North Sea

Figure 39: Reference values for the thickness increasing due different species

It is worth to mention that there are a lot of factors (i.e water temperature, salinity) that influence on the amount and variety of the marine growth in a certain site.

The following thickness of marine growth is considered as reference value:

Marine Growth	
Water Depth (m)	Thickness (mm)
+2 to -40	100
below -40	50

Table 42: Thickness increasing due to marine growth in GoM

The density of marine growth is assumed to be 1.325 kg/m³.

4.9.5 Seismicity

USGS (U.S Geological Survey [B10]) is used within this section as the main source of information for the seismicity assessment in Gulf of Maine site. In this reference, historical data of seismicity and earthquakes has been registered since 1811 up to 2012. Only two remarkable events were registered in the Gulf of Maine:

- The first in 1904, with a Magnitude of 5,1 on the Richter Scale.
- A second in 2006 with a Magnitude of 3,8 on the Richter Scale.

Therefore, Gulf of Maine selected site can be considered as a location with a very low seismic activity.

5 Site C: Severe Environmental Conditions (Reference Location: West of Barra - Scotland)

This location has been selected as representative for an upper bound, in terms of environmental conditions, for the development of floating platforms. Given the high power available in this part of Scotland's coastline it is not expected that this suggestion can be taken forward as readily as others. The resource available and the acceptable levels of constraint, however, make this an attractive and potentially fruitful proposition.

5.1 Location

West of Barra selected site is located 19km West of Barra Island immediately within the 12 NM limit. The coordinates of the central point within the proposed area are [56.886°N, 7.948°W](#). This site has been identified by Marine Scotland as a potential area where tests sites for deep water floating technology could be located [C1] .

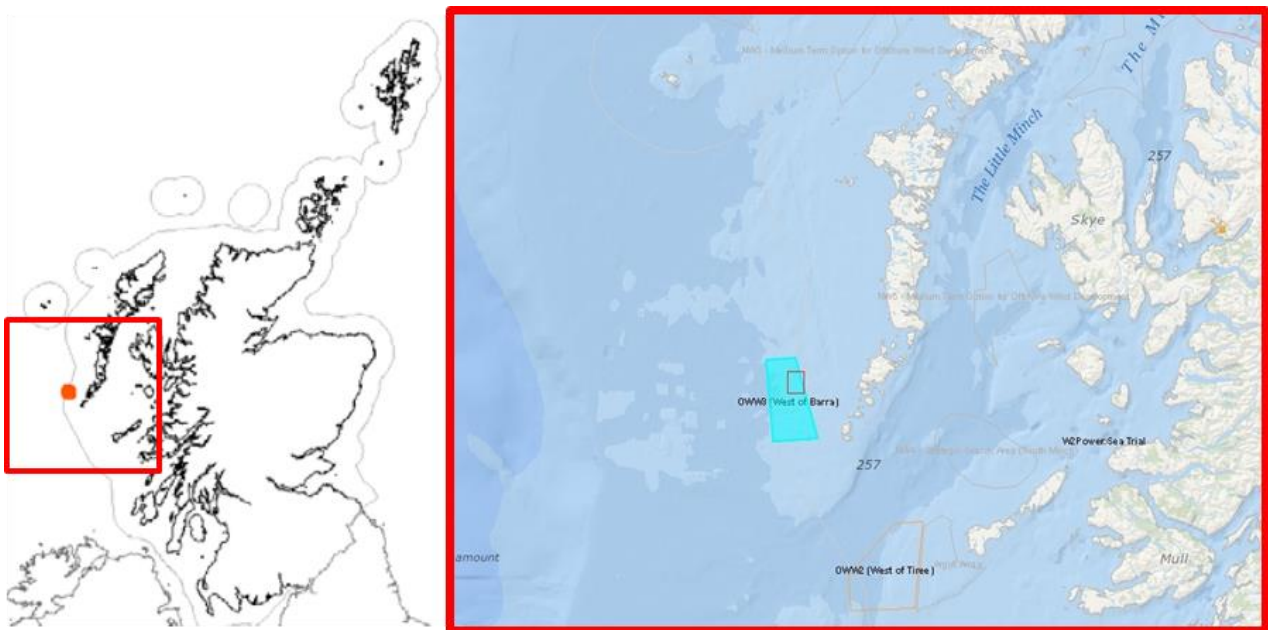


Figure 40: West of Barra proposed site location

For the characterization of the oceanographic and meteorological conditions of the selected site in West of Barra, it is used the information provided in HSE studies (which are based on the Fugros GEOS measured data).

5.2 Water Depth and Water Levels

5.2.1 Bathymetry

It shall be remembered that the defining depth for West of Barra site was selected among the WP1 members to be enough differentiated from the characteristic depths of the other two selected sites as well as to be representative of this certain site in **100 m**. This selected site has a mean depth of 95 m

with a maximum depth towards its western side of 118m. This site deepens towards the continental shelf edge which lies at 65km due west. The shallower spots can be found at the south east corner with 56 m water depth.

The sloping is gentle between 0 and 3 degrees and runs in an east-west direction.

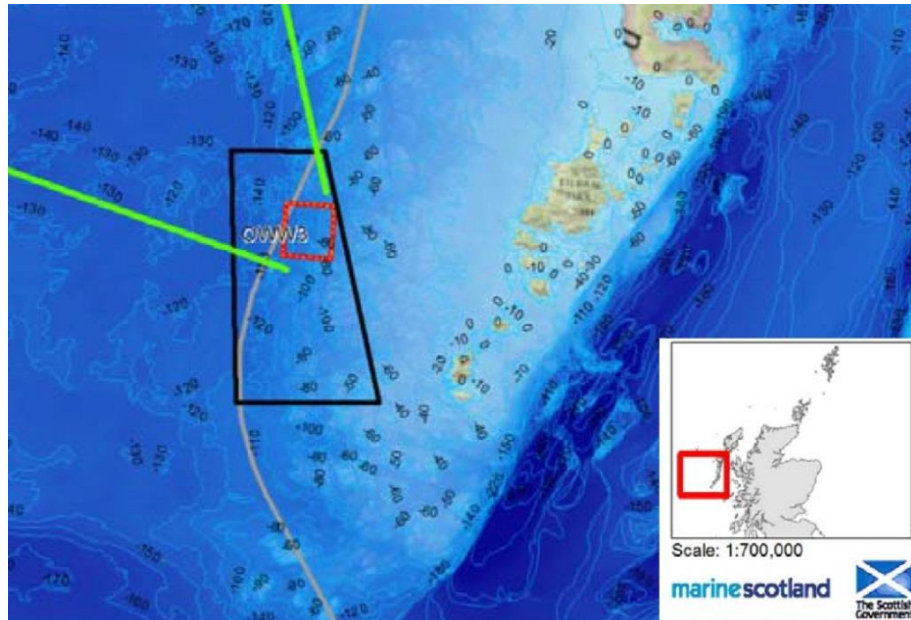
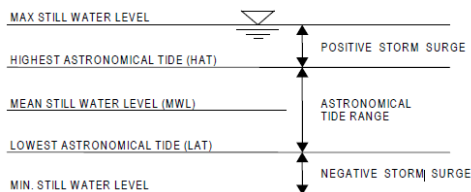


Figure 41: West of Barra proposed site location

5.2.2 Water Levels

Sea water levels for the astronomical tide range have been obtained from measured values at West of Barra location. Positive and negative 50-year return period storm surges have been estimated following recommendations given in [C2] .

Summary of West of Barra's water levels as defined in DNV-RP-C205 are given below.



HSWL	[m]	4.16
HAT	[m]	3.16
MSL	[m]	2.32
LAT	[m]	-1.48
LSWL	[m]	-2.48

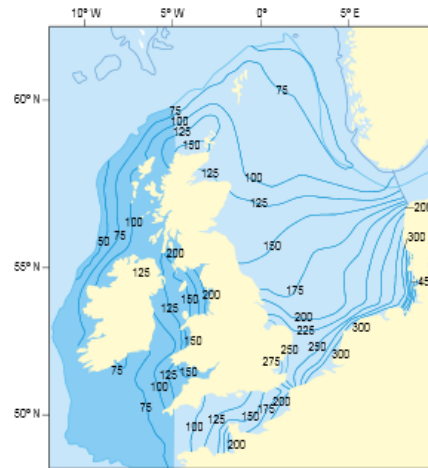


Figure 42: Fifty-year average storm surge elevations (cm) for sea areas around UK. Flather 1987.

5.3 Wind Climate

As expected given the location of this site, the wind resource is high and reliable through the year, presenting an annual mean power density of around $1,3 \text{ kW} \cdot \text{m}^{-2}$. The main reference considered when evaluating the wind conditions of West of Barra site is the report issued by Fugro [C2] .

Since all data contained in the information source is based on 1-hour averaged wind speed at 10 m above MSL, results obtained in this analysis have been extrapolated to the target height (through the study of the wind shear profile). Moreover, due to available data is given in 1-hour averaged values; conversion from 1-hour to 10-min averaged values to adjust to standards recommendations has been performed by means of the ratios provided in [C2] .

5.3.1 Wind Shear Profile

5.3.1.1 Operational Conditions' Profile

Relationship between the wind speeds at two different heights is given by the wind shear profile. In order to select the most accurate profile law for the selected site, single values of the annual mean wind speed at several heights taken from the Atlas prepared by ABPmer [C3] , have been compared with different wind shear profiles recognized in main standards (See Figure 43).

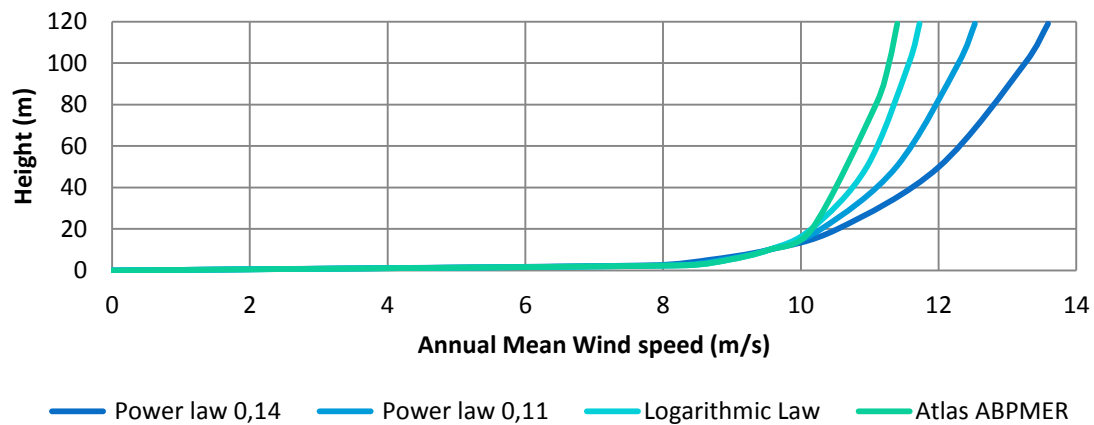


Figure 43: Comparison between the different wind speed profiles versus the guidance value of ABPMER.

The reference values for the annual mean wind speed considered in this analysis are, 9,54 m/s @10m, 10,15 m/s @19,5m, 11,09 m/s @80m and 11,28 m/s @100m.

The figure above, illustrate how **the logarithmic law** fits better the data gathered for the site of West of Barra, having only a 2,6% difference between the estimated value and the reference value at 119m height.

$$V(z) = V_{hub} \cdot \frac{\ln(z/z_0)}{\ln(z_{hub}/z_0)}$$

The resulting 10 minutes mean wind speed profile is the following:

Normal Wind Profile	
Height	Speed
[m]	[m/s]
10	9,50
20	10,16
50	10,97
100	11,58
119	11,74

Table 43: Normal wind speed profile for WoB site

5.3.1.2 Extreme Conditions' Profile

In absence of further detailed information in regards to 50 years return period wind speed at different heights, wind shear profile in extreme conditions have been considered to follow a power law relationship with alpha factor ($\alpha = 0,12$) as recommended in ABS and DNV standards for offshore locations.

$$V(z) = V_{hub} \cdot (z/z_{hub})^{0.12}$$

The extreme wind speed profile would be the following:

Extreme Wind Profile	
Height	Speed
[m]	[m/s]
10	26,47
20	35,63
50	44,13
100	48,97
119	50,00

Table 44: Extreme conditions wind speed profile

5.3.2 Wind Speed Distribution

Available information at West of Barra site is composed of 31 years 1-hour averaged hindcast data over the following periods:

- Winters (October-March): from 10/1964 to 3/1995.
- Summers (April-September): from 1977 to 1979 and from 1989 to 1994.
- Significant summer storms (April-September).

5.3.2.1 Histogram

Following table summarizes the exceedance probability for the 1-hour averaged wind speed values obtained from the aforementioned time series.

Wind Speed [m/s]	$0,0 < u_{10} < 0,3$	100,00 %
	$0,3 < u_{10} < 1,6$	100,00 %
	$1,6 < u_{10} < 3,4$	99,97 %
	$3,4 < u_{10} < 5,5$	95,82 %
	$5,5 < u_{10} < 8,0$	82,67 %
	$8,0 < u_{10} < 10,8$	60,08 %
	$10,8 < u_{10} < 13,9$	35,00 %
	$13,9 < u_{10} < 17,2$	14,79 %
	$17,2 < u_{10} < 20,8$	4,20 %
	$20,8 < u_{10} < 24,5$	0,73 %
	$24,5 < u_{10} < 28,5$	0,11 %
	$28,5 < u_{10} < 32,7$	0,00 %

Table 45: Wind speed exceedance probability in WoB selected site

5.3.2.2 Weibull distribution parameters

A Weibull distribution has been fitted by the Least Square Method (LSM) to the exceedance probability values provided in (5.3.2.1). The parameters defining this Weibull function are given below so it is the correlation coefficient.

Weibull Parameters	
Scale coefficient	9,089
Shape coefficient	2,096
Location coefficient	1,400
R^2	0,999

Table 46: Weibull distribution parameters

Figure 44 shows the comparison between the raw data distribution (blue) and the associated Weibull distribution (red) from the table above, through graphic representations (on the left the probability density function and on the right the cumulative probability) which shows the level of accuracy obtained with the considered parameters.

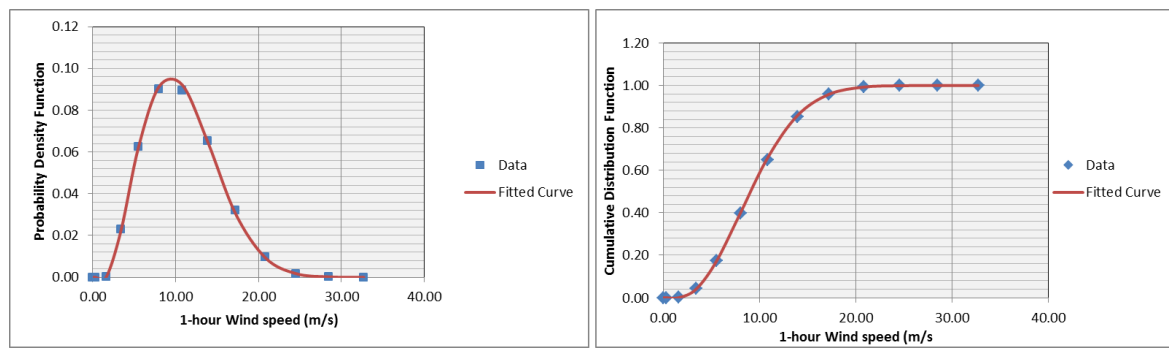


Figure 44: 1-hour averaged frequencies distribution and Weibull fit for West of Barra

5.3.2.3 Annual Average Wind Speed

Annual 1-hour averaged wind speed for West of Barra is **9,50 m/s** at 10 m height. This value has been obtained from reference [C2] from a 31-year time series of hindcast data. Table below provides in addition to the annual averaged wind speed, the monthly averaged value, and giving further sensitivity in regards to its seasonal variation.

	Month	Average speed [m/s]
Annual average wind speed	Jan	11,85
	Feb	11,36
	Mar	11,35
	Apr	8,86
	May	7,20
	Jun	7,26
	Jul	7,48
	Aug	7,65
	Sept	9,14
	Oct	9,85
	Nov	10,76
	Dec	11,24
Total		9,50

Table 47: Annual average wind speed

5.3.2.4 10-min Reference Wind Speed (1, 5, 10 and 50 years return period)

The extreme wind speed, denoted by V_{ref} in the IEC standards, is defined as the value of the highest wind speed, averaged over 10 minutes, with an annual exceeding probability of 2% (50-years return period).

In order to estimate the V_{ref} value it is necessary to use a method that extrapolates the horizon of the extreme wind speed prediction to 50 years. Since there is no standardized method in the norm to assess extreme wind speed, the EWTSII method has been applied and taken as reference although its results have been compared against outcomes obtained by other methods (i.e. the factor-5 method). The selection of this method has been made, based on the WAUDIT questionnaire [C4] performed by CENER over a sample of 72 wind analysts from 48 different organizations of 13 European countries, that concluded that the EWTSII was the preferred method among the wind energy community (selected by the 54% of participants).

5.3.2.4.1 EWTSII method

The EWTSII method was developed by Winkelaar (1999) to infer the extreme wind speed distribution based on the parameters of the parent Weibull distribution. This method works reasonably well with sites with high Weibull shape factor but is not so suitable for heavy tailed distributions, typical of complex terrain.

In the absence of 10-minute wind speed data the aforementioned parent Weibull distribution has been obtained from [C5] [C4], by means of fitting the distribution function to the 1-hour wind speed data (NEXT's grid node 15609) using the Least Square Method (LSM). Using the EWTSII method the v_{ref} is given by means of the following mathematical expression [C6]

$$\frac{V_{ref}}{V_{ave}} = \frac{1}{\Gamma(1 + 1/k)} \cdot \left[-\ln \left\{ 1 - \exp \left(\frac{\ln(1 - 1/T_r)}{n} \right) \right\} \right]^{\frac{1}{k}}$$

Where (T_r) is the return period associated to the V_{ref} value, (n) is the number of independent storms and (k) is the K-Weibull parameter.

In order to determine the number of independent storms contained in the sample, a storm analysis has been undertaken using time series obtained from MERRA and ERAI atmospheric numerical models. Same reference point as NEXT's grid node (15690) has been selected for the independent storm analysis performed in these two hindcasted time series to minimize the impact of local effects in the estimation of the number of independent storms parameter. Since the aforementioned formulae provides the V_{ref} value as a function of the averaged wind speed, conversion from 1-hour averaged to 10-min averaged and from 10 m. reference height to the hub height (119 m.) have been conducted prior to the application of this method.

Return Period	Max. annual wind speed (1-hour average @ 10 m. height)	Max. annual wind speed (10-min average @ Hub height – 119 m.)
1	29.36	40.07
10	36.09	50.42
20	37.06	52.01
V_{ref} 50	38.25	53.79

Table 48: Reference wind speed at hub height calculation

Same procedure has been performed for the MERRA and ERAI hindcasted time series mentioned above. Input data is again 1 hour averaged at 119 m height for both of these sources; hence, these values have been passed to 10 min averaged using same assumptions as described above summarizes the results obtained for the V_{ref} using as input both MERRA and ERAI hindcast time series.

Input Data	Vref (1-hour average)	Vref (10-min average)
MERRA – Timeseries	44.79 [m/s]	47.34 [m/s]
ERAI – Timeseries	48.16 [m/s]	51.10 [m/s]

Table 49: MERRA and ERAI reference wind speed comparison

5.3.2.4.2 Summary

The V_{ref} at West of Barra location has been estimated taken as reference the EWTSII method as it has been identified as the preferred method among the wind energy community. However, additional approaches have been also undertaken to support the validity of the results provided in this report.

Due to the inherent limitations of available data results show a significant variability depending on the method used. To overcome this uncertainty, the EWTSII method has been used under two additional non-public data sources (MERRA and ERAI hindcast time series), obtaining similar results for the V_{ref} value as per these same results obtained from data available in [C4] . Through comparison it has been noticed that results obtained by the use of the EWTSII method with aggregated NEXT's grid node 15906 data provided in [C5] provides higher values of the V_{ref} , likely due to the conservative coefficients that have had to be used to convert 10 m. reference height wind speeds to the target hub height reference height (119 m.). Furthermore, it shall be noticed that all baseline information gathered for the wind speed at West of Barra's are given in an hourly averaged basis, hence, these values have had to be converted to a 10 min averaged values using conservative coefficients provided in [C5] , therefore it should be expected that these values slightly overestimates the real V_{ref} value.

Results obtained for the V_{ref} value by means of the EWTSII method indicates that it will range between 47.34 and 53.79 [m/s]. Taking into account what mentioned in the previous paragraph and given that the DTU 10MW reference wind turbine is classified as class: (IC), a **Vref value of 50 m/s will be associated to this West of Barra location with an occurrence probability of 0.02 % (50 year return period).**

V_{REF} VALUE ASSOCIATED TO WEST OF BARRA
50 (m/s)

Table 50: Final WoB Vre value considered

5.3.3 Wind Direction

Wind direction distributions have been derived by sorting wind speed into eight directional sectors centered on the cardinal points of the compass. The sector boundaries (relative to true North) are as follows:

Directionality Sectors	
N	337.50° to 22.49°
NE	22.50° to 67.49°
E	67.50° to 112.49°
SE	112.50° to 157.49°
S	157.50° to 202.49°
SW	202.50° to 247.49°
W	247.50° to 292.49°
NW	292.50° to 337.49°

Figure 45: WoB direction legend

5.3.3.1 Wind Rose

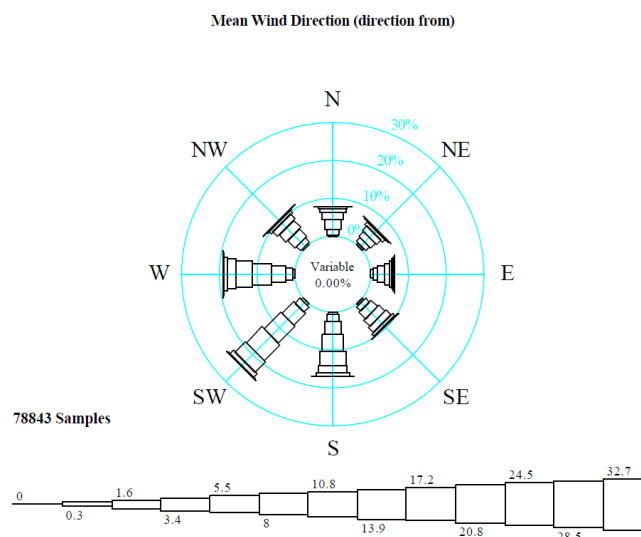


Figure 46: West of Barra wind rose (Mean wind speed at 19,5 m ASL)

5.3.3.2 Scattergrams of ten minutes average wind speed

As taken from [C2], the following table gathers up the mean wind speed for the different incoming wind direction sectors. The direction, clockwise from true North, is from which the wind is blowing. Direction measures were performed for 1-hour average direction at a height of 19,5 m (despite the mean wind speed, that is given at 10 m height).

Mean Wind Speed at 10 m [m/s]	Mean Wind Direction [°] ¹⁹							
	0	45	90	135	180	225	270	315
0,00-0,30								
0,30-1,60	2	4	6	2	3	4	2	
1,60-3,40	333	413	403	430	535	469	366	326
3,40-5,50	1091	1138	1116	1229	1515	1527	1576	1170
5,50-8,00	1932	1385	1395	1782	2668	3385	3049	2217
8,00-10,80	1421	1294	1105	1841	3496	4850	3750	2016
10,80-13,90	928	641	510	1408	2847	4729	3451	1420
13,90-17,20	397	215	192	605	1576	3035	1782	549
17,20-20,80	52	55	68	162	561	948	731	160
20,80-24,50	5	5	1	30	86	182	132	46
24,50-28,50					3	27	46	10
28,50-32,70							1	1
32,70-51,50								

Table 51: Wind direction in WoB selected site

5.3.4 Turbulence Intensity

If based on the turbine class: (IC) for the DTU 10MW wind turbine; The IEC-61400-1 [C7] provides indicative values of the turbulence standard deviation and turbulence intensity for the normal turbulence model (NTM). It shall be noticed that these values are not site-specific but external conditions that must have been considered in the design of the wind turbine.

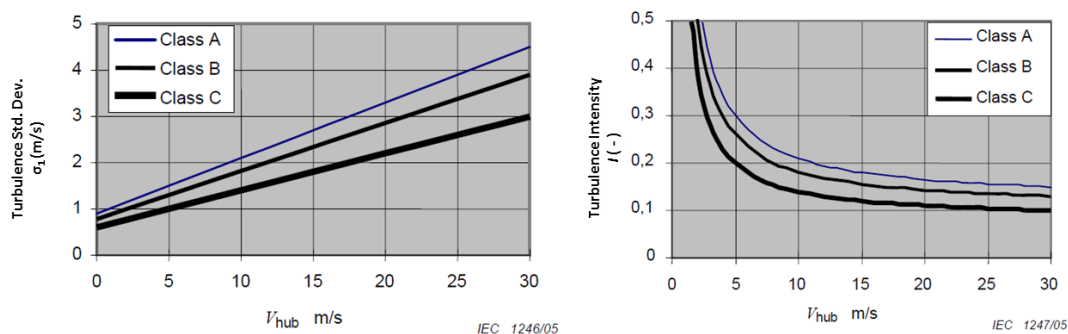


Figure 47: Turbulence Intensity for different Wind Turbine Classes, as defined in IEC-61400-1 [C7]

5.3.5 Spectral Density

In absence of more detailed information and following DNV recommendations, it has been decided to assume the Kaimal model as the most representative of wind spectral density at West of Barra. The Kaimal model provides the distribution of wind energy over the different frequencies.

¹⁹ Considered bin size: 45°

5.3.6 Wind Gust Characteristics

No information is available at West of Barra site in regards to wind gust. Hence, reference is made to IEC-61400-1 [C7] [C6], where it can be found mathematical models that allow characterizing wind gust and accounting for its effects on the design load cases (DLC's). Required information for generating the aforementioned numerical models is provided within this document; time-average conversion may be required in order to obtain certain parameters, if so reference is made to [C5] [C4].

5.4 Wave Climate

Wave power density at this site is also strong, since no shelter is available from the north-east swell. The annual mean wave power density is $44,13 \text{ kW m}^{-1}$. Such energy will require innovative approaches to ensure the devices remain in place and maintaining power generation.

The main reference that is considered when evaluating the wave conditions of West of Barra site is the report issued by [C2]

Within this document, the grid point 15609 ($56,609^{\circ}\text{N}$, $7,996^{\circ}\text{W}$) is the one considered due to its proximity to the proposed site.

5.4.1 Significant Wave Height- Peak Period Distribution

5.4.1.1 *Hs/Tp Scattergrams*

The significant wave height and spectral peak period frequency distributions show the joint frequency of occurrence of wave height and period for an average year.

Hs [m]	Tp [s]																					
	0-1	1-2	2-3r	3-4r	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22
0.0-0,5			1																			
0.5-1,0				129	337	681	581	1242	774	341	88	24	11	40	28	11						
1.0-1,5				18	589	1721	1189	2403	3333	1824	754	284	120	23	20	6						
1.5-2,0					21	1260	1855	1644	2765	2720	1444	744	235	131	50	27	3	2				
2.0-2,5				1	4	164	1804	1614	1843	2055	1773	1273	562	222	40	31		4	1			
2.5-3,0					1	8	607	1536	1290	1462	1659	1184	686	338	101	40	1	8	3			
3.0-3,5							85	989	970	1014	1170	1140	749	265	167	61	11	9	1			
3.5-4,0							10	397	846	859	971	873	754	319	221	76	20	5				
4.0-4,5							1	53	646	706	744	893	791	353	206	127	30	4				
4.5-5,0								8	221	529	586	790	659	414	167	76	44	27	4			
5.0-5,5									44	340	558	517	441	250	252	56	9	10	4			
5.5-6,0									7	169	293	433	424	214	182	75	9	16				
6.0-6,5									1	67	101	315	263	186	100	54	21	13	6			
6.5-7,0										3	42	220	301	218	101	35	17	13	2			
7.0-7,5											15	106	160	156	69	54	17	1				
7.5-8,0											8	32	145	117	59	50	1	4				
8.0-8,5												10	121	112	67	37		3				
8,5-9,0												3	115	148	62	25	4	2				
9,0-13,5													78	277	321	197	15	21				

Table 52: Significant wave height – Peak period frequency

5.4.1.2 Wave height's associated Weibull Distribution

Data provided by [C2] has been statistically analysed and fitted to a Weibull curve. Parameters of this best fit distribution function are given below as well as its correlation factor. Figure 48 illustrates the accuracy of Weibull distribution fit.

Weibull Parameters	
Scale coefficient	0,744
Shape coefficient	0,976
Location coefficient	0,015
R^2	0,990

Table 53: Defining parameters of the Weibull distribution associated to WoB wave height distribution

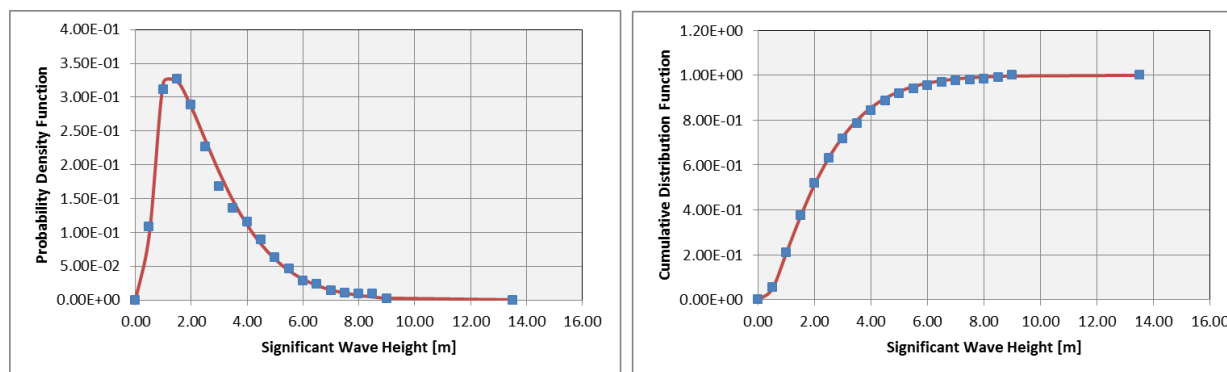


Figure 48: Correlation between Significant wave height raw data and its associated Weibull distribution

5.4.1.3 Wave characteristics reference values (1, 5, 10 and 50 years return period)

Based on Weibull distribution and assuming 3 hour storms sea states, significant wave heights associated to 50, 20, 10 and 1 year return period are provided in the following table. For each of these values, the wave peak period has been extrapolated as the most probable value associated to that height, in order to do so a curve fitting analysis (see below) has been performed to allow for determining the most probable values to be associated to those wave heights that are not contained within the available data.

Wave Climate	Return period [years]	Significant Wave Height [m]	Tp [s]
	50	15,6	12-18 ²⁰
	20	14,7	15,0
	10	14,0	14,9
	1	11,5	14,3

Table 54: Reference values of significant wave height in WoB and its associated peak periods

For each of these values, the wave peak period has been extrapolated as the most probable value associated to that height, in order to do so a curve fitting analysis (see below) has been performed to allow for determining the most probable values to be associated to those wave heights that are not contained within the available data.

²⁰ This range of period has been selected taking into account the highest wave measured in site, which can be checked in the scatter diagram of previous sections. If a certain value of the peak period is needed, it can be calculated with the extrapolation procedure detailed below, which gives the most probable peak period associated to the 50 year return period wave of 15,2 s.

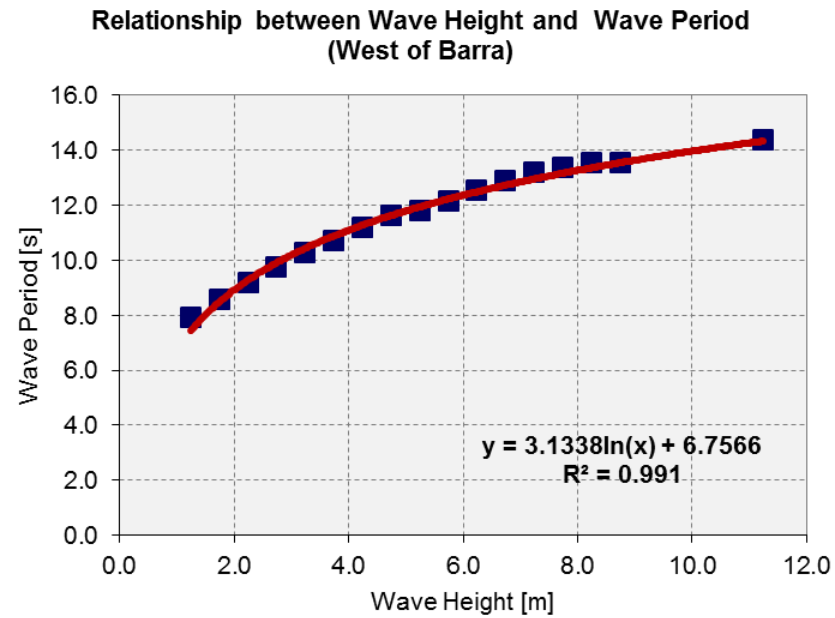


Figure 49: Extrapolation curve for Peak period-Significant wave height correlation

5.4.2 Wave Direction

Wave direction distributions have been derived by sorting incoming wave directions into eight directional sectors centred on the cardinal points of the compass. The sector boundaries (relative to true North) are as follows:

Directionality Sectors	
N	337.50° to 22.49°
NE	22.50° to 67.49°
E	67.50° to 112.49°
SE	112.50° to 157.49°
S	157.50° to 202.49°
SW	202.50° to 247.49°
W	247.50° to 292.49°
NW	292.50° to 337.49°

Figure 50: WoB direction legend

5.4.2.1 Wave Rose

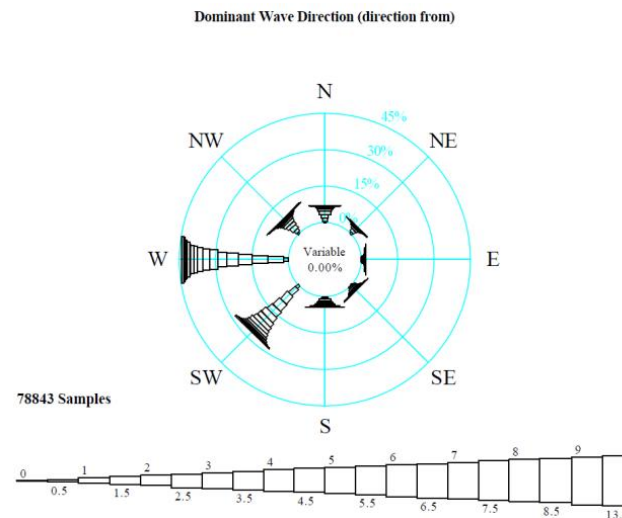


Figure 51: West of Barra wave rose (Significant wave height)

5.4.2.2 Wave direction Scatter Diagrams

The following table gathers up dominant wave direction for the different incoming wave direction sectors. The direction, clockwise from true North, is from which the waves are travelling. The dominant wave direction is the direction associated with the peak of the total wave spectrum.

Significant Wave Height [m]	Dominant Wave Direction [°] ²¹							
	0	45	90	135	180	225	270	315
0,00-0,50				1				
0,50-1,00	410	568	151	44	59	1100	1435	520
1,00-1,50	1159	950	330	326	311	2933	5156	1119
1,50-2,00	1344	597	324	376	490	3279	5111	1380
2,00-2,50	1029	356	190	541	684	2951	4507	1133
2,50-3,00	624	217	89	403	499	2375	3755	962
3,00-3,50	343	175	63	227	371	1972	2870	610
3,50-4,00	234	107	65	170	294	1587	2544	350
4,00-4,50	151	44	58	117	301	1343	2292	248
4,50-5,00	104	14	14	81	160	1221	1705	226
5,00-5,50	73	12	13	28	136	870	1191	158
5,50-6,00	56	2	8	26	84	542	1030	74
6,00-6,50	9		11	24	35	339	658	51
6,50-7,00				1	15	316	582	38
7,00-7,50					9	192	348	29
7,50-8,00					9	114	268	25
8,00-8,50						100	233	17
8,50-9,00						105	237	17
9,00-13,50						190	664	55
13,50-20,00								

Table 55: Wave direction

²¹ Considered bin size: 45°

5.4.3 Wave height occurrence distribution

The table below summarizes the occurrence probability associated to the significant wave height for each month in the selected locations for the wind farm design in the West of Barra. This occurrence probability is show for each month and can be used to determine the percentage of time at which a particular wave height is not exceeded.

		Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec
Significant Wave Height [m]	Hs <= 0	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Hs <= 0,5	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
	Hs <= 1	0,31%	0,77%	0,73%	1,41%	13,86%	11,84%	13,49%	12,46%	8,49%	0,97%	0,39%	0,12%
	Hs <= 1,5	0,93%	5,29%	3,39%	14,07%	46,22%	43,16%	48,88%	43,83%	23,29%	13,28%	5,86%	2,63%
	Hs <= 2	6,50%	12,49%	9,90%	36,66%	70,21%	71,90%	68,88%	68,36%	45,34%	33,10%	15,20%	8,33%
	Hs <= 2,5	18,59%	24,17%	22,30%	58,58%	81,82%	86,54%	85,97%	82,36%	60,05%	52,03%	25,65%	22,07%
	Hs <= 3	31,02%	35,12%	35,23%	72,20%	89,96%	93,75%	93,74%	89,23%	70,83%	65,55%	42,33%	37,05%
	Hs <= 3,5	40,14%	46,77%	46,16%	81,81%	94,16%	97,70%	97,24%	93,31%	78,78%	75,40%	55,86%	49,97%
	Hs <= 4	49,49%	58,35%	56,75%	87,63%	96,53%	98,75%	98,98%	95,77%	85,54%	81,42%	68,83%	61,11%
	Hs <= 4,5	58,37%	70,20%	65,75%	91,88%	98,30%	99,34%	99,61%	97,91%	90,09%	86,21%	78,77%	72,51%
	Hs <= 5	68,08%	77,91%	74,23%	94,22%	99,09%	99,71%	99,90%	99,61%	92,90%	90,56%	85,62%	80,87%
	Hs <= 5,5	75,94%	83,28%	80,27%	96,08%	99,45%	99,92%	100,00%	99,87%	95,34%	93,31%	91,37%	85,77%
	Hs <= 6	81,07%	87,81%	85,08%	97,79%	99,76%	100,00%	100,00%	99,91%	97,02%	95,25%	94,89%	89,87%
	Hs <= 6,5	85,00%	90,33%	89,02%	98,35%	99,99%	100,00%	100,00%	100,00%	97,85%	96,56%	96,40%	92,11%
	Hs <= 7	88,79%	92,39%	92,34%	98,92%	100,00%	100,00%	100,00%	100,00%	98,29%	97,65%	97,61%	94,12%
	Hs <= 7,5	90,78%	94,05%	94,29%	99,27%	100,00%	100,00%	100,00%	100,00%	98,50%	98,25%	98,56%	95,22%
	Hs <= 8	92,45%	95,07%	95,68%	99,54%	100,00%	100,00%	100,00%	100,00%	98,73%	98,64%	99,04%	96,12%
	Hs <= 8,5	93,83%	95,88%	97,00%	99,78%	100,00%	100,00%	100,00%	100,00%	99,03%	98,89%	99,23%	96,97%
	Hs <= 9	95,52%	96,89%	97,98%	99,86%	100,00%	100,00%	100,00%	100,00%	99,49%	99,10%	99,48%	97,77%
	Hs <= 13	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Table 56: Significant wave height occurrence probability distribution

This occurrence distribution can be also represented within the following graphic. This occurrence probability is show for each month and can be used to determine the percentage of time at which a particular wave height does not exceed a certain value.

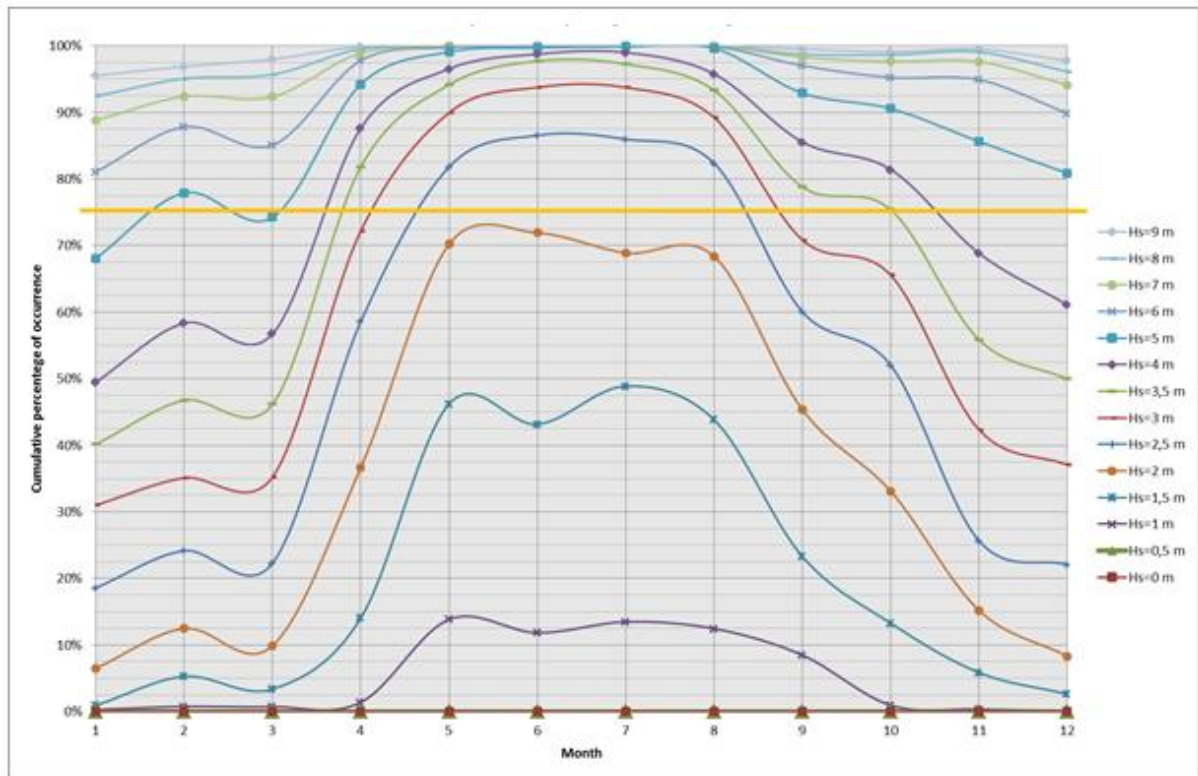


Figure 52: Significant wave height occurrence probability graphic representation

5.4.4 Wave spectrum

No information from West of Barra is available on site to determine the most suitable wave spectrum to characterize wave climate. However, based on its location it can be assumed, as indicated in [C8] such oceanic regions of the Northern Europe are likely to be subjected to swell waves that have moved out of the area in which they were generated (North of the Atlantic Ocean). Hence, pointing to Pierson-Moskowitz as the most advisable wave spectrum model for this specific location.

5.5 Wind-Wave Combined Conditions

Only the correlation between the mean wind speed and the significant wave height is available for West of Barra site.

5.5.1 Wind-Wave climate Scattergrams

Significant Wave Height [m]	Mean Wind Speed at 10 m [m/s]												
	0,00-0,30	0,30-1,60	1,60-3,40	3,40-5,50	5,50-8,00	8,00-10,80	10,80-13,90	13,90-17,20	17,20-20,80	20,80-24,50	24,50-28,50	28,50-32,70	32,70-51,50
0,00-0,50						1							
0,50-1,00		5	1054	2316	897	14	1						
1,00-1,50		14	1061	4055	5701	1444	9						
1,50-2,00		1	632	2070	5126	4736	335	1					
2,00-2,50		3	284	1083	3024	5167	1809	21					
2,50-3,00			139	468	1570	3645	2933	169					
3,00-3,50			58	197	762	2080	2981	550	3				
3,50-4,00			40	119	398	1190	2586	997	21				
4,00-4,50			4	33	193	747	2157	1324	96				
4,50-5,00			2	10	81	409	1441	1418	164				
5,00-5,50			1	10	32	184	767	1180	301	6			
5,50-6,00				1	22	87	452	869	370	21			
6,00-6,50					4	39	207	532	320	25			
6,50-7,00					3	12	116	463	334	24			
7,00-7,50						12	64	276	194	31	1		
7,50-8,00						2	38	195	137	44			
8,00-8,50						2	22	152	138	33	3		
8,50-9,00						2	10	98	201	45	3		
9,00-13,50							6	106	458	258	79	2	
13,50-20,00													

Table 57: Wind- Wave combined distribution: Hs-u₁₀ correlation

Based on this information, it has been performed some studies to try to preview the most probable wind speed associated to each significant wave height. This formula is intended to ease the calculation of the met-ocean conditions required within the WP7 to establish the DLCs.

To ensure the best correlation possible with the real sea state conditions (represented by the achieved raw data), mainly two equations have been considered:

- Second order polynomial equation:

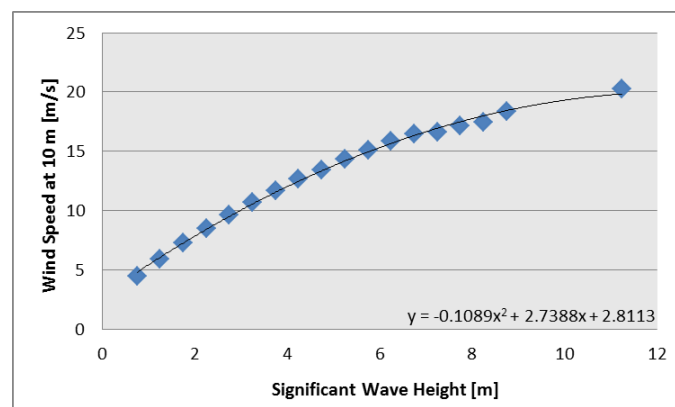


Figure 53: Second order polynomial equation

- Third order polynomial equation:

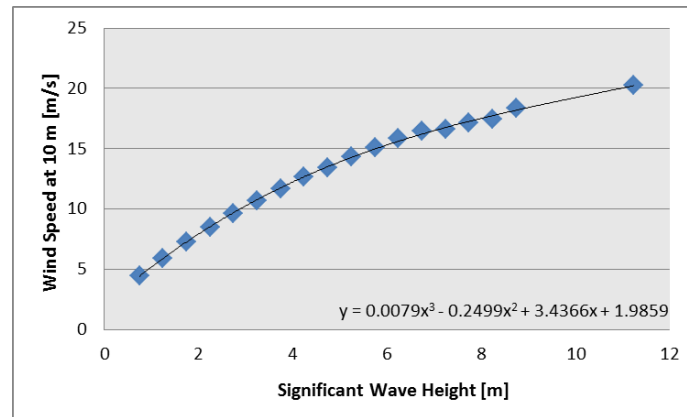


Figure 54: Third order polynomial equation

Following table summarizes the different values checked during the selection of the most accurate relation between the significant wave height and its associated wind speed from the aforementioned possibilities:

		Wind speed [m/s]	
		2 nd Order	3 rd Order
Significant wave height [m]	1	5,44	5,18
	3	10,05	10,26
	5	13,78	13,91
	7	16,65	16,51
	9	18,64	18,43
	11	19,76	20,07
	13	20,01	21,78
	15	19,39	23,97

Table 58: Comparison of both equations proposed for the wind-wave correlation

It is demonstrated that the difference between the two equations is not significant inside the range of significant wave height represented in the scatter diagram. However, when calculating the associated wind speed to significant wave heights that are out of this aforementioned range of values, **the 3rd order polynomial equation** is better adjusted to the expectable values for the wind speed.

5.5.2 Wind-Wave missalignments

No met-ocean data is available about the correlation of wind direction and wave direction. On that base, the wind-wave misalignment should be defined in WP7 based on standards for the development of the required DLCs.

5.6 Currents Data

Surrounding Scotland seas are directly affected by oceanic circulation due to its position at the UK Continental Shelf. The steep bathymetry of the continental slope acts as a barrier between oceanic regions and the shelf sea systems, reducing the amount of water that can travel from the deeper waters of the North Atlantic into the shallower waters on the continental shelf. Tidal currents are stronger than the non-tidal in most of Scottish areas and these are better predictable. Moreover, tidal currents are intensified in localised areas usually where the flow is constrained by topography. This includes areas such as between Orkney and Shetland, the Pentland Firth, off the Mull of Kintyre and Hebrides where tidal streams can be as high as 3.5-4.5 m/s.

The non-tidal circulation on the shelf west of Scotland, (the Scottish Coastal Current) is mainly northwards. However this circulation is strongly affected by winds and density-driven coastal currents and jets, which can lead to large changes in currents and even a reversal of this general pattern for short periods.

Besides this general overview, no site-specific current data is available at West of Barra. Hence currents at site location have been characterized based on available met-ocean numerical model data provided in [C5] [C4] and making certain assumptions in regards to wind generated currents following main recognized standards [C5] [C9]

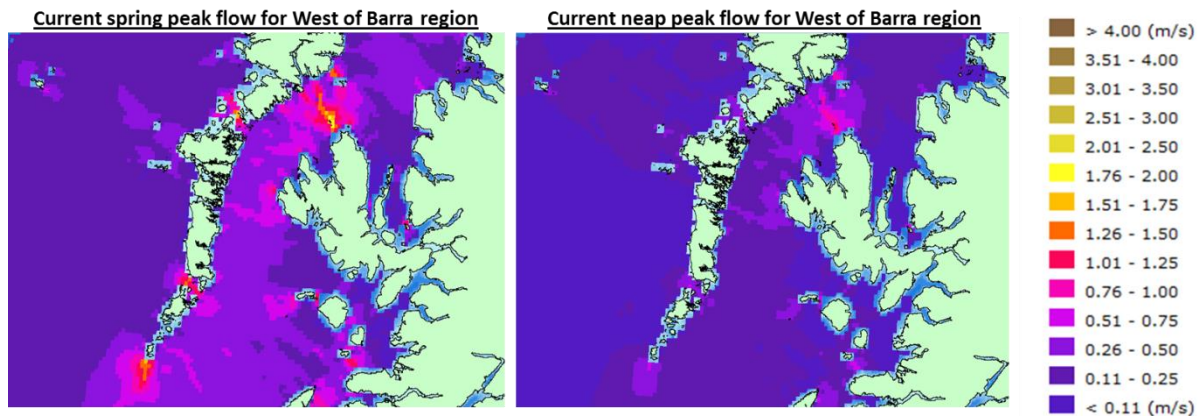


Figure 55: Current peak flow for the West of Barra region: Current spring peak (left), Current neap peak (right)

5.6.1 Current induced by wind (1-/5-/10-/50-year event)

Wind induced current has been estimated following recommendations given in [C9] . Hence, it has been assumed that there is a direct relationship between the 1 hour averaged wind speed at 10 m height and the current speed at surface given by the following mathematical expression:

$$V_{c_{wind}}(s_0) = k \cdot U_{1hour}$$

Where (k) coefficient will be taken as 0.03 in order to account for the worst case scenario and obtain a safety side current speed value.

The surface current induced by wind associated to the 50 years return period, will be determined from the 1 hour averaged wind speed with an exceedance probability of 0.05% (50-years return period) applying the aforementioned formula. Same procedure will be applied for the estimation of wind induced current speeds associated to 1 and 50 years return period as given in the table below.

Return period	Wind induced current speed
	(@ surface) [m/s]
1	0,88
50	1,15

Table 59: Current induced by wind speed at sea surface

The direction associated to these current speed values will be taken in accordance with following sections, as the most probable wind direction obtained from the scatter diagram (5.3.3.2). Therefore wind induced current direction will be taken as West to East direction for all cases.

5.6.2 Deep water current (1-/5-/10-/50-year event)

Indicative values of depth averaged currents at West of Barra location has been obtained from [C5] . Values provided in this reference, are associated to the 50 years return period of the spring tidal current and the storm surge current components. Hence, the resulting depth averaged current speed obtained in this clause will be calculated as the vectorial sum of each of the terms commented above.

Under these assumptions, the 50 year return period mean spring tidal current (representative for the biggest currents happening twice in a month) has been taken from reference [C5] as 0.44 m/s value and North-East direction. Analogously, the 50 year return period storm surge current component indicative value is 0.60 m/s heading North.

As indicated in first paragraph, the resulting 50 years return period combined current speed is obtained by vectorial summation of the aforementioned terms. Moreover, it has been possible to obtain the 1 year return period by applying correction factors given in [C5] as shown in table below.

Return period	Tidal current		Storm surge current		Combined current	
	Vc [m/s]	Dir [°]	Vc [m/s]	Dir [°]	Vc [m/s]	Dir [°]
1	0,39	50	0,53	0	0,84	21
50	0,44	50	0,6	0	0,94	21

(*) 0° direction is relative to North.

Table 60: Deep water current speed at sea surface

5.6.3 Current speed profile

Since no information is available at West of Barra regarding the current speed profile, reference is made to DNV recommended practices [C9] . Based on this standard the two following mathematical models have been used to estimate the variation of current speed with depth depending on the type of current under consideration:

Current induced by wind

$$v_{c,wind}(z) = v_{c,wind}(0) \cdot \left(\frac{d_0 + z}{d_0} \right) \text{ for } -d_0 \leq z \leq 0$$

Where d_0 is taken as half of the water depth at West of Barra following DNV recommendations, hence $d_0 = 50 \text{ m}$

Tidal current

$$v_{c,tide}(z) = v_{c,tide}(0) \cdot \left(\frac{d + z}{d} \right)^\alpha \text{ for } z \leq 0$$

Resulting current speed profiles for each of the currents defined in section 5.6.1 and 5.6.2 are given in the following tables for the 1 year and 50 year return period currents respectively. Last column of this table represents the vectorial summation of the aforementioned component.

Depth	WIND COMPONENT	TIDAL & SURGE COMPONENT	TOTAL CURRENT SPEED PROFILE
[m]	[m/s]	[m/s]	[m/s]
0	0.881	1.023	1.570
-10	0.705	1.008	1.421
-20	0.528	0.992	1.279
-30	0.352	0.973	1.147
-40	0.176	0.952	1.029
-50	0.000	0.928	0.928
-60	0.000	0.900	0.900
-70	0.000	0.864	0.864
-80	0.000	0.817	0.817
-90	0.000	0.741	0.741
-100	0.000	0.000	0.000

Figure 56: Total current speed profile associated to the 1 year return period probability.

Depth	WIND COMPONENT	TIDAL & SURGE COMPONENT	TOTAL CURRENT SPEED PROFILE
[m]	[m/s]	[m/s]	[m/s]
0	1.053	1.158	1.822
-10	0.842	1.141	1.642
-20	0.632	1.122	1.471
-30	0.421	1.101	1.312
-40	0.211	1.078	1.169
-50	0.000	1.051	1.051
-60	0.000	1.018	1.018
-70	0.000	0.978	0.978
-80	0.000	0.924	0.924
-90	0.000	0.839	0.839
-100	0.000	0.000	0.000

Figure 57: Total current speed profile associated to the 50 years return period probability

5.6.4 Current Direction

In absence of more detailed statistical information in regards to current direction, only most probable current speed directions can be provided. Based on tidal current direction provided in Table 60 and assuming that wind induced current direction will be driven by wind's direction, the following table provides most probable headings with respect to the North.

	Most probable heading	
	Direction [°]	Compass Coordinates
Wind induced current	90	E
Tidal & Surge current	21	NNE

(*) 0° direction is relative to North.

Table 61: Most probable current direction

5.6.5 Current characteristic reference values (1, 5, 10 and 50 years return period)

From the information described in sections above (especially 5.6.1 and 5.6.2), the characteristic current speeds with a return period of 1 and 50 years is calculated as the sum of its components:

Current Speed extreme values	Return period [years]	Current speed [m/s]
	50	1,822
	1	1,570

Table 62: Reference values for current speed in WoB

5.7 Soil Conditions

West of Barra site lies entirely over rocky sea bottom that has been deepened by glacial scouring action. The predominant rock type is Lewisian gneiss, which has a similar hardness to granite.

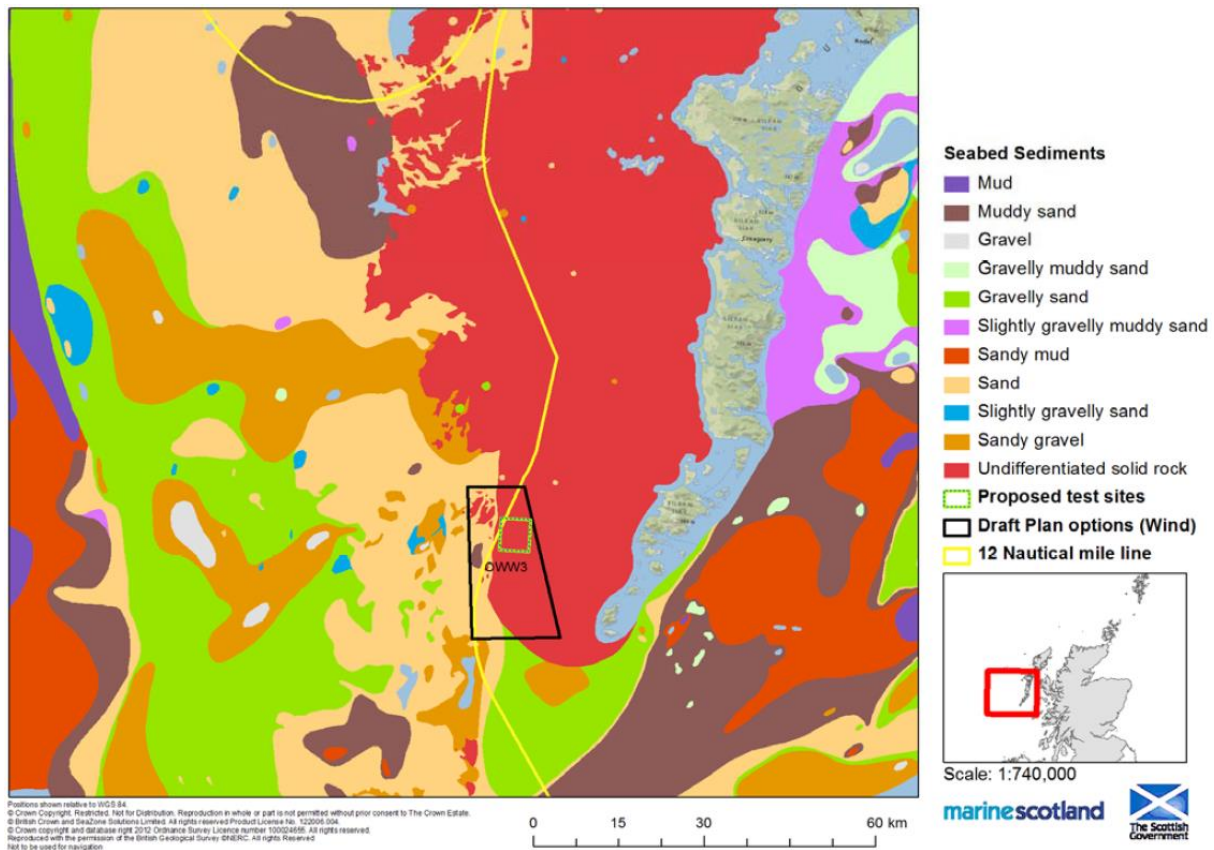


Figure 58: West of Barra seabed general characteristics

A multibeam bathymetry is provided from a nearby area located approximately 30 km North from West of Barra site. This information has been gathered from Joint Nature Conservation Committee report [C10] [C8] and is meant to serve as reference of further insights in regards to the soil conditions that should be found in West of Barra.

As shown in Figure 58, seabed is dominated by extensive areas of highly fractured bedrock. The fractures form a regular network of gullies, some as wide as 130m with sides up to 30m in height. Although not extensively ground-truthed, the gullies appear to be infilled by coarse sands.

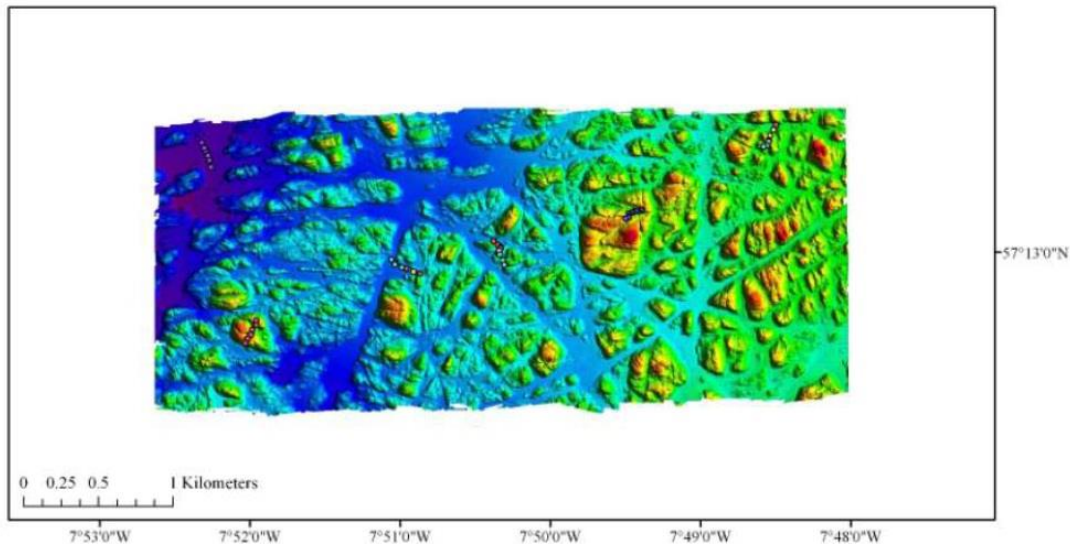


Figure 59: Multibeam bathymetry of an area in the vicinity of West of Barra. Source JNCC [C10]

With all these general information gathered for the seabed characterization, and following with the same trend of the soil characterization mentioned in section 2.3, it is defined a standard soil profile for de characterization of the West of Barra site seabed.

Soil Profile Characteristics			
Layer	Soil Type	Layer Length [m]	Compressive strength [MPa]
1	Rock (Basalt)	20	200

Table 63: Soil profile designed for WoB selected site

5.8 Other Environmental Conditions

Environmental (climatic) conditions other than wind can affect the integrity and safety of wind turbines. The following environmental conditions, at least, shall be taken into account and the resulting action stated in the design documentation.

5.8.1 Ice (sea spray/precipitation)

No specific information is available on site. However in the following clause it has been summarize relevant information that should be taken into account for this environmental condition during the design. These values shall be taken as indicative information, which have been provided by [C5] and are based on conservative assumptions made from available data sources and calibrated numerical models.

5.8.1.1 Sea ice and Iceberg

Based on the aforementioned information, sea ice and iceberg collision needs not to be considered in the design of offshore structures in the UK waters, since there is no evidence to suggest that these events may occur. Figure 60 shows limit areas in the North-West Europe region for sea ice and collision with icebergs events with an associated annual probability of exceedance of 10^{-2} and 10^{-4} .

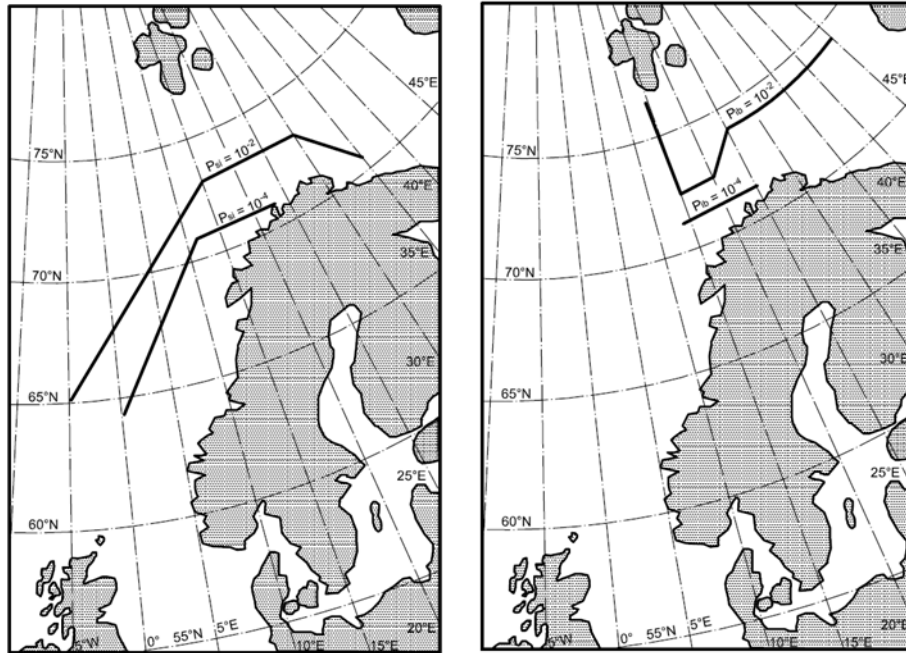


Figure 60: Annual probabilities of exceedance for sea ice (left) and collision with icebergs (right). ISO 19901-1:2005

5.8.1.2 Ice and snow accumulation

Snow accumulation is more likely to occur than ice at West of Barra. Snow may settle on non-horizontal windward-facing parts of an installation if the snow is sufficiently wet.

On vertical surfaces it is only likely to stay in position as snow for a few hours although it may then freeze, hence remaining as ice. Snow accumulation will affect all exposed elements above the splash zone.

Ice may form on an offshore structure through the following mechanisms: (i) freezing sea spray, (ii) freezing fog and super-cooled cloud droplets, (iii) freezing rain and (iv) freezing old wet snow. On a 50-year return period criterion, and based on the information provided in [C5] [C4], there is no reason to believe that any of the aforementioned mechanisms to form ice on offshore structures is of any significance at the West of Barra site.

Figure 61 provides indicative values for snow and ice accumulation at 57,7 ° N.

Structural element	Wet snow		Ice from freezing sea spray		Ice from frozen snow	
	Thickness (mm)	Density (kg/m ³)	Thickness (mm)	Density (KG/m ³)	Thickness (mm)	Density (kg/m ³)
<i>At latitude 57.7°N[#]</i>						
Tubular member below deck level [*]	-	-	25	850	-	-
Tubular member below deck level ⁺	40	500	-	-	30	900
Lattice member above deck level	40	500	-	-	25	900
Horizontal surface	200	100	-	-	-	-

The values in the table have been predicted from a model covering North Sea waters west of 3° E. There is no available data for other UK designated waters but it is suggested that the values in the table may also be used for comparable latitudes west of the UK mainland. The thickness relates to increase in radius in relation to tubular members.

^{*} Icing on members below deck level from freezing sea spray is likely to start about 4-7m above MSL at the thickness indicated and reduce to zero thickness at a height of about 9-15m above MSL

⁺ Snow and ice from freezing of old wet snow will accumulate on members below deck level only above the splash/spray zone.

[#] Because of the absence of data no estimates can be made of the depth of accumulations north of 57.5°N. However, the values for 57.5°N are sufficiently conservative to be used for UK designated waters north of this latitude.

Figure 61: Extreme snow and ice accumulations. Source OTH 2001/010

5.8.2 Sea Water Characteristics

No specific information is available on site. Sea water properties information has been therefore gathered from nearby location when possible or by means of general climatic Atlas information.

5.8.2.1 Temperature

Sea temperatures around Scotland are affected by local climatic conditions (heat flux with atmosphere) and the heat transferred to the shores of Scotland by ocean currents (advective effects). Sea surface temperatures vary with an annual cycle, lagging behind the cycle of atmospheric temperature by around one month.

As shown in Figure 62, coldest sea water temperatures are recorded in the Scottish Continental Shelf (region 7 in the map) ranging from 6°C in winter to 14°C in summer. Since no on-site data is available, sea-surface temperature data has been obtained from the nearest possible location: The Isle of Lewis, located around 120 Km North East from West of Barra.

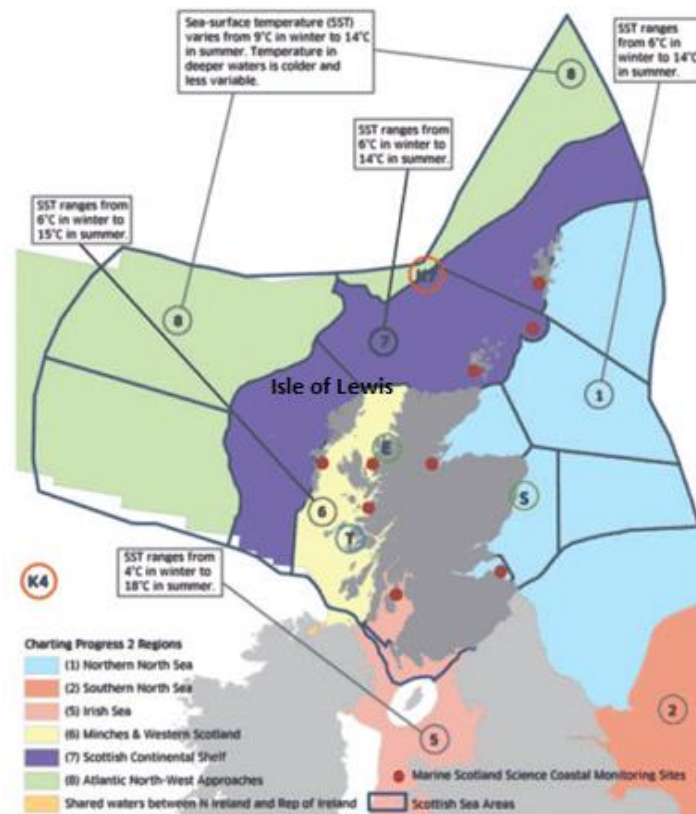


Figure 62: Scottish sea areas water temperature range

The monthly seawater temperatures provided in Figure 63 shall be taken as indicative values, although as shown in Figure 64, provided data belongs to the Minches & Western Scotland region, sea-surface temperature ranges seems to be similar, ranging from 6°C in both regions to 14°C and 15°C for the Scottish Continental Shelf and Minches & Western Scotland regions respectively. Hence, West of Barra's sea-surface temperatures may be expected to have lower maximum values and slightly lower average values. Minimum sea surface temperature values should be however similar to those provided in this report.

The measurements for the sea temperature in Isle of Lewis, Scotland are provided by the daily satellite readings provided by the NOAA. These temperatures given are surface temperature (SST); hence temperature variation with depth should be further estimated if needed. Reference values for the seafloor temperature are provided in (ISO 1990-1:2005), in this case values for the West of Shetland area may be taken as reference, ranging these values from -2°C to +12°C.

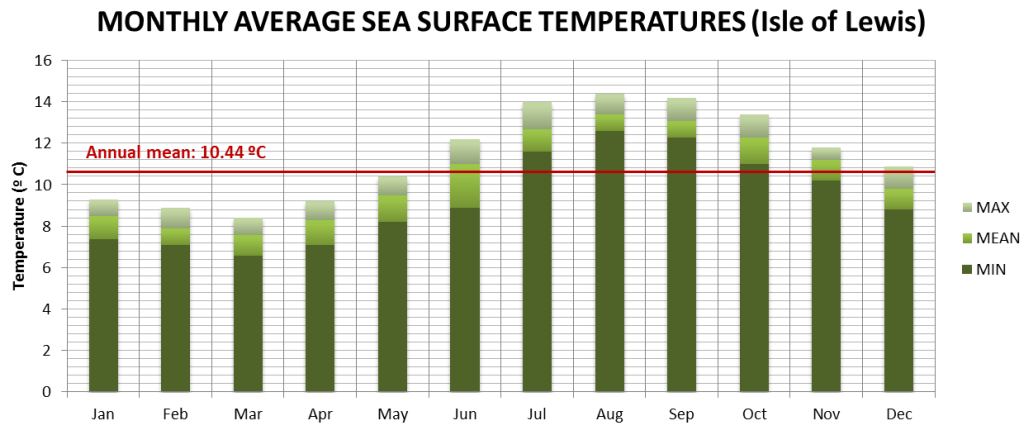


Figure 63:. Isle of Lewis average monthly seawater temperature. Source: NOAA

It shall be noted that sea surface water temperature has shown an ever increasing trend during the last 25 years around the coast of Scotland, and indeed the whole of the United Kingdom. Although the rate of increments shows geographic variation, it has been generally greater than 0,2 °C per year and based on the data provided by the NOAA over a period of 25 years (1985-2009) this rate of increment can be estimated for the location of West of Barra on 0,35 °C per year.

In regards to extreme sea surface temperature, an estimation of these values has been obtained from [C5] which are based on the examination of data from VOF ships and fixed offshore weather stations. Figure 64 provides plot contours of the extreme max and min probable sea surface temperature values, these graphs cannot be more accurate than +/- 1 °C, however they provide valuable indicative values for the extreme max and min sea-surface temperature, 18°C and 4°C respectively.

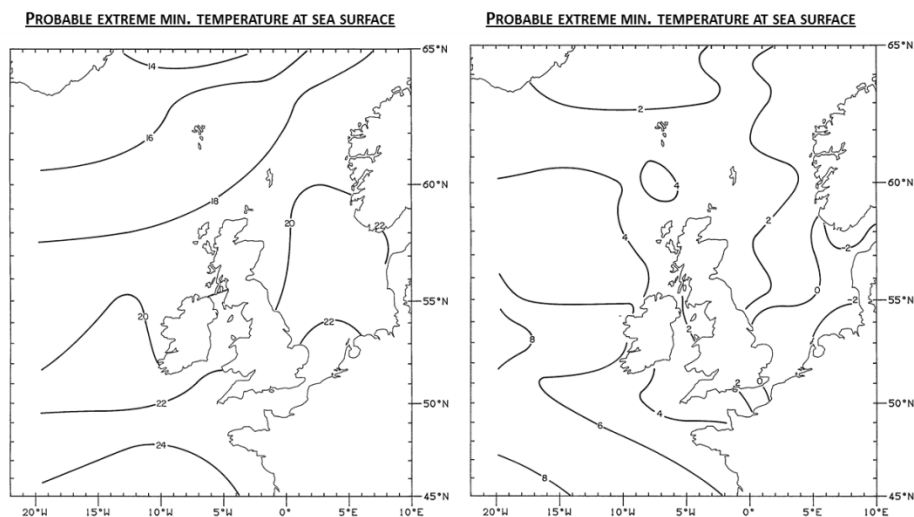


Figure 64. Estimates of probable extreme minimum (left) and maximum (right) sea surface temperatures.

5.8.2.2 Density

The density of the sea water at 1 standard atmosphere can be computed from the practical salinity and water temperature by applying “the one atmosphere International equation of state of seawater”. Figure 65 provides water density values as a function of salinity and temperature.

Based on the previous clauses of the document and applying the aforementioned equation, water density at surface has been estimated in 1.025,97 kg/m³.

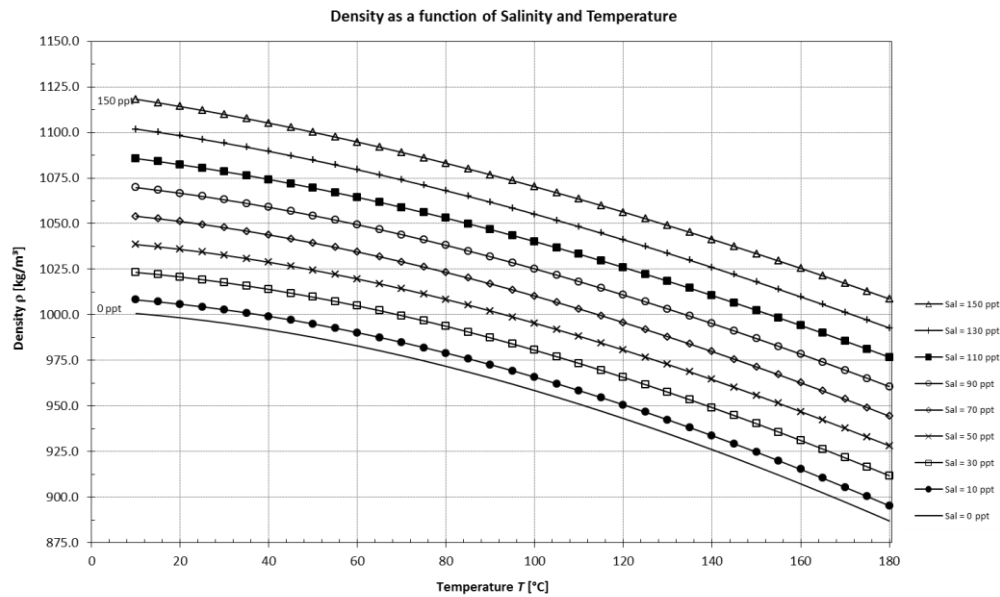


Figure 65: Density as a function of salinity and temperature.

5.8.2.3 Salinity

The surface salinity in the Sea of The Hebrides may slightly vary seasonally. Salinity values from west to east across the Hebridean shelf as high salinity Atlantic water becomes mixed with fresher coastal water derived from land run-off. In the southern part of the Sea of the Hebrides the stronger influx of Atlantic water results in higher salinities south-east of Barra.

As shown in Figure 66, in winter, the lower salinity values extend down through the water column, but horizontal stratification develops in the spring and becomes most pronounced in the summer, especially across the middle and outer shelf (Region 15), where wind and the tides are not sufficiently energetic to mix the water column.

Besides this surface salinity variability, salinity at deeper depths seems to remain fairly constant at 35 psu (practical salinity units), since the 35,0 isohaline which is taken to indicate Atlantic-origin water is usually located at 50-80 m depth although it may brake to surface during spring season.

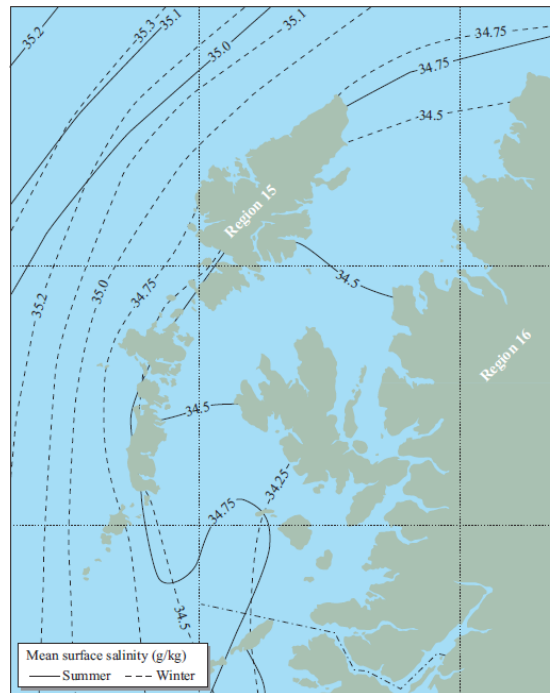


Figure 66: Mean surface salinity of seawater in summer and winter (in g/kg) of total dissolved salt). Extracted from the Coastal Directories Series. JNCC [C11]

5.8.3 Air Characteristics

No specific information is available on the certain selected site. Air properties' information have been gathered from specialized offshore environmental report [C5] , and indicative values provided by recognized standards.

5.8.3.1 Temperature

The Offshore Technology Report 2001/010 [C5] [C4] , has been taken as main reference for estimating air temperature at West of Barra location. The information provided is based on hindcast data generated from numerical models and the examination of data from VOF ships and fixed offshore weather stations.

Table below summarizes indicative values for the probable extreme maximum/minimum air temperatures at West of Barra location as well as the lowest observed daily mean air temperature (LODMAT). The values provided in the table below may vary in +/- 1° C.

Air temperature at West of Barra		
Probable extreme max air temperature	22	[° C]
Probable extreme min air temperature	-4	[° C]
LODMAT	-4	[° C]

Table 64: Air temperature in West of Barra at sea level

5.8.3.2 Density

No specific information is available on site. Air density may be considered as 1.225 kg/m³ following IEC-61400-1 [C7] .

5.8.4 Marine Growth

No specific information is available on-site in regards to marine growth. Based on [C1] West of Barra is located over the following EUNIS habitats as illustrated in Figure 67:

- Atlantic and Mediterranean low energy circalittoral rock (A4.3)
- Faunal communities on deep low energy circalittoral (A4.33)
- Faunal communities on deep moderate energy circalittoral rock (A4.27)

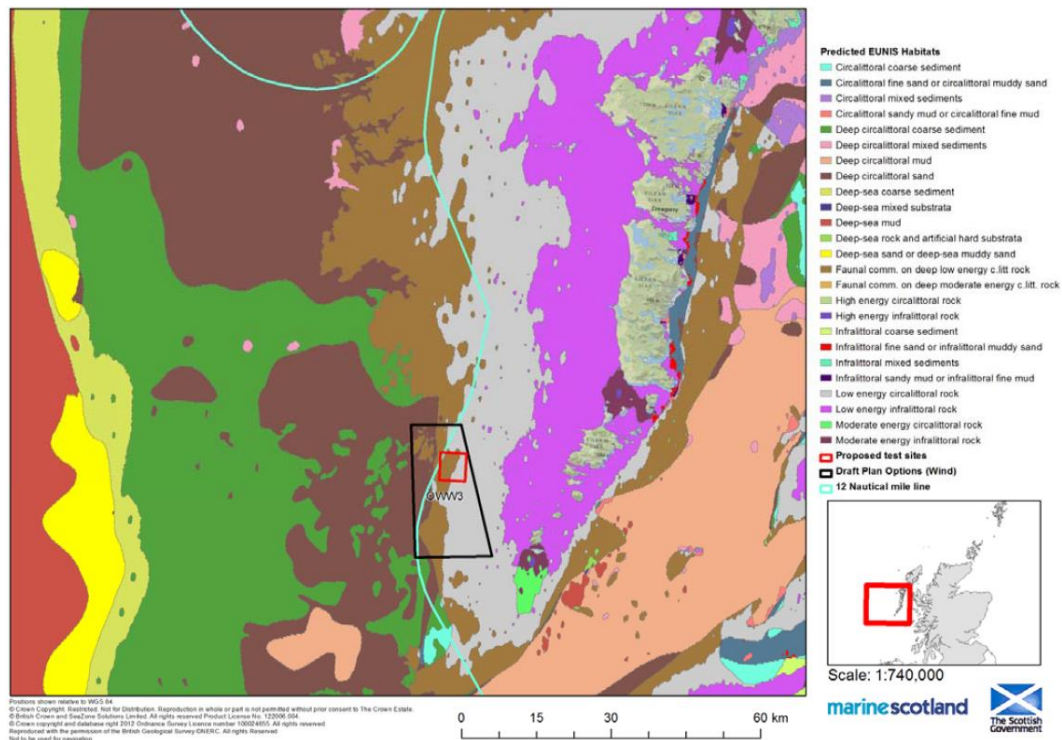


Figure 67: West of Barra predicted EUNIS habitats

Moreover, biological studies conducted on several oil and gas platforms in the North Sea, may provide a valuable source of information in order to estimate marine growth rates. The following table taken from [C5] provide reference values obtained from those studies.

Type	Settlement season	Typical growth rates	Typical coverage (%)	Typical terminal thickness	Depth range (relative to MSL)	Comments
<i>Hard fouling</i>						
Mussels	July to October	25 mm in 1 year 50 mm in 3 years 75 mm in 7 years	100%	150 to 200 mm	0 to 30 m	But faster growth rates are found on installations in the southern North Sea
Solitary tubeworms	May to August	30 mm (in length) in 3 months	50-70%	About 10 mm (tubeworms lay flat on the steel surface)	0 to mudline	Coverage is often 100%, especially on new structures 1 to 2 years after installation. Tubeworms also remain as a hard, background layer when dead
<i>Soft fouling</i>						
Hydroids	April to October	50 mm in 3 months	100%	Summer: 30 to 70 mm Winter: 20 to 30 mm	0 to mudline	A permanent hydroid 'turf' may cover an installation and obscure the surface for many years
Plumose anemone	June to July	50 mm in 1 year	100%	300 mm	-30 m to -120 m (0 to -45 m on platforms in southern North Sea)	Usually settle 4 to 5 years after installation and can then cover surface very rapidly. Live for up to 50 years
Soft coral	January to March	50 mm in 1 year	100%	About 200 mm	-30 m to -120 m (0 to -45 m on platforms in southern North Sea)	Often found in association with anemones
<i>Seaweed fouling</i>						
Kelp	February to April	2 m in 3 years	60-80%	Variable, but up to 3 m	-3 m to -15 m	May be several years before colonisation begins but tenacious holdfast when established. Present on some installations in northern and central North Sea

Figure 68: Reference values for the thickness increasing due different species

It shall be noticed that many factors influence on the amount and type of marine growth. These factors include physical factors such as temperature, salinity, water depth and wave action, as well as biological factors such as predators, larval supply, nutrient and food availability, biology and physiology of the individual species. Hence the values provided herein shall be used with caution since some of these values might be significantly vary from one location to the other.

The following terminal thickness of marine growth is recommended according to NORSOK N-003:

Marine Growth	
Water Depth (m)	Thickness (mm)
+2 to -40	100
below -40	50

Table 65: Estimated maximum thickness of marine growth

Marine growth's density may be assumed 1.325 kg/m³.

5.8.5 Seismicity

The UK does not have a significantly high seismicity activity; however it may pose a moderate potential hazard to sensitive installations. Figure 69 contains on the left side onshore and offshore UK's earthquakes recorded up to 2007 and on the right side the revised seismic hazard map for the UK.



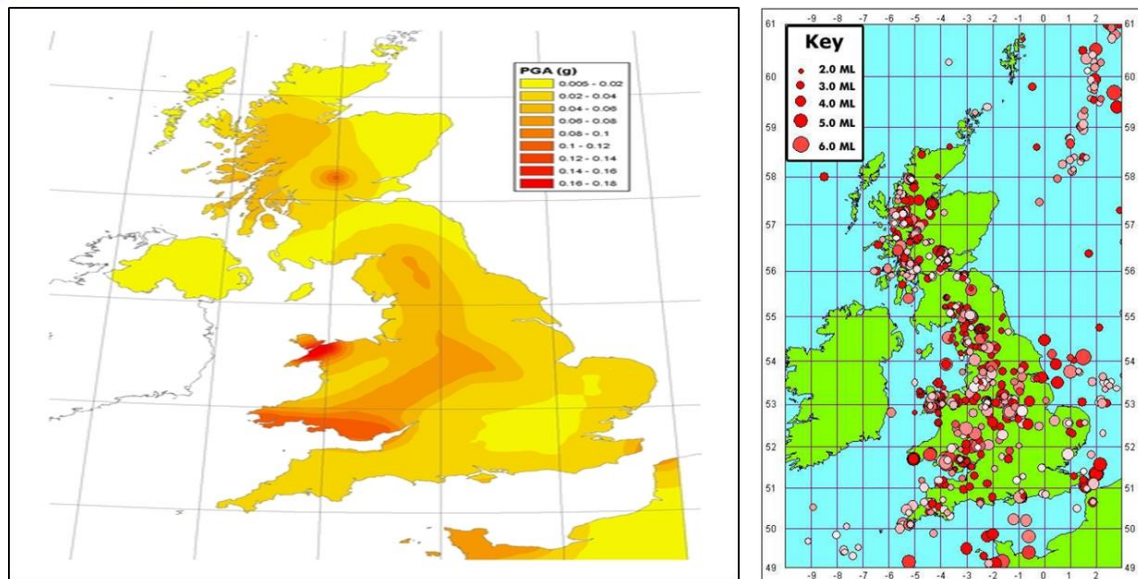


Figure 69: Seismic Hazard Map for the UK (Left side). Historical earthquakes recoded at UK until 2007.

As illustrated in previous figure, the UK areas subjected to highest seismic hazard is Snowdonia followed by South of Wales. Moreover, studies carried out by EQE International Limited in conjunction with NORSAR (Oslo) for the Health and Safety Executive (HSE) classifies the West of Barra area as sparsely active.

Table below provides indicative values of peak ground accelerations for 100,200, 500, 1000 and 10.000 years return periods at West of Barra location. This information has been obtained from reference [C12]

RETURN PERIOD	PGA ^(*)	ANNUAL EXCEED- ANCE PROBABILITY
[years]	[m/s ²]	[-]
100	0,11	1x10 ⁻²
200	0,18	5x10 ⁻³
500	0,28	2x10 ⁻³
1.000	0,40	1x10 ⁻³
10.000	1,30	1x10 ⁻⁴
(*) Peak ground acceleration		

Table 66: Indicative values of peak ground accelerations

6 Selected Site Reference Data Summary

Met-ocean key parameters						
Modelling DNV-OS-J101 [B5] Sec3		Parameters	Gulf of Maine	West of Barra	Golfe de Fos	units
Wind		U _{mean,hub}	10,46	11,74	-	m/s
	EWM (3.2.5.4)	U _{10,hub,50-yr} (*)	44,0	50,0	37,0	m/s
		U _{hub,50-yr} =1,4·U _{10,hub,50-yr}	61,6	70,0	52	m/s
		U _{hub,1-yr} =0,8·U _{hub,50-yr}	48,9	56,0	42	m/s
		σ _U =0.11·U _{10,hub}	4,8	5,5	4,1	-
Waves	ESS (3.3.4.7)	H _{s,50-yr} ; [T _{p,min} ; T _{p,max}]	10,9 [9-16]	15,6 [12-18]	7,5 [8-11]	m; [s;s]
		H _{s,1-yr} ; [T _{p,min} ; T _{p,max}]	7,7 [9-16]	11,5 [12-18]	4 [6-11]	m; [s;s]
Current	ECS	V _{c,50-yr}	1,13	1,82	0,9	m/s
Water level	MSL		130 (+1,624)	100 (+2,32)	70 (+0,74)	m
	EWLR	HSWL _{50-yr}	4,319	4,16	1,13	m
		LSWL _{50-yr}	-0,795	-2,48	-0,35	m
Soil Type (compressive resistance)			Medium	Hard (rock)	Soft	-
Soil condi- tions	Compressive Strength		-	200 (Basalt)	-	Mpa
	Layer length		-	20	-	m
	Friction angle Layer 1		35 (very dense sand)	-	30 (dense sand)	phi/kPa (**)
	Layer 1 length		4	-	3	m
	Friction angle Layer 2		60 (soft clay)	-	60 (soft clay)	phi/kPa (**)
	Layer 2 length		6	-	4	m
	Friction angle Layer 3		200 (stiff clay)	-	250 (stiff clay)	phi/kPa (**)
	Layer 3 length		9	-	10	m
Others (*)	Water tem- perature (3.8.3.1)	T _{max,50-yr}	22,5	19	30	°C
		T _{min,50-yr}	1	3	5	°C
	Marine growth DNV-RP-C205 6.7.4.2	Thickness	See section 3.3.8	See section 3.3.8	See Section 3.3.8	mm
		density	1.325	1.325	1.325	Kg/m³
(*) Density and temperature data are measured at 1m depth.						
(**) phi(°) if sand Cu (kPa) if clay						

Figure 70: Summary table for selected sites characterization

7 References

7.1 Site A: Moderate Environmental Conditions. Golfe de Fos

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